DOCKET
09-AFC-7
DATE OCT 06 2010
RECD. OCT 06 2010

STATE OF CALIFORNIA

Energy Resources Conservation and Development Commission

In the Matter of:

APPLICATION FOR CERTIFICATION FOR THE PALEN SOLAR POWER PROJECT

DOCKET NO. 09-AFC-7

THE CENTER FOR BIOLOGICAL DIVERSITY

OPENING TESTIMONY, EXHIBIT LIST, EXHIBITS, AND PROOF OF SERVICE

October 6, 2010

Lisa T. Belenky, Senior Attorney
Center for Biological Diversity
351 California St., Suite 600
San Francisco, CA 94104
Direct: 415-632-5307
Fax: 415-436-9683
lbelenky@biologicaldiversity.org

Ileene Anderson
Public Lands Desert Director
Center for Biological Diversity
PMB 447, 8033 Sunset Boulevard
Los Angeles, CA 90046
(323) 654-5943
ianderson@biologicaldiversity.org

INTRODUCTION

Intervenor Center for Biological Diversity (the "Center") provides this Opening Testimony regarding the application for certification of the proposed Palen Solar Power Project.

All of the testimony presented herein was prepared by the person testifying, a signed declaration and resume has also been provided for each person.

Center Attorney Lisa T. Belenky and Public Lands Desert Director Ileene Anderson assisted in compiling this testimony and the documents submitted. An Exhibit List and copies of the documents referenced in the opening testimony are filed concurrently with this testimony.

The Center for Biological Diversity reserves the right to supplement and/or revise this testimony at any time up to and including the close of the evidentiary hearings. Moreover, many of the factual issues discussed in this Opening Testimony involve both legal and factual questions while others are predominately legal issues. Therefore, the Center respectfully reserves the right to address all disputed issues identified at the hearings through testimony, rebuttal, cross-examination, or at later stages of this process including in briefing following the evidentiary hearing.

Pursuant to the discussion at the Prehearing Conference on October 5, 2010, the Center may also file additional Opening Testimony on two additional disputed issues -- Air Quality and Soil and Water -- on or before October 15, 2010.

The Center for Biological Diversity also requests that the Committee take official notice of documents cited in testimony which are published by the California Energy Commission and are available on the Commission website. Those documents are listed after the Exhibit List.

TESTIMONY SUBMITTED

1. **Testimony of Bill Powers, P.E., Regarding Alternatives, Declaration, Resume**

2. **Testimony of Ileene Anderson Re: Impacts to Sensitive Plants and Wildlife, from the Proposed Palen Solar Power Project, Declaration, and Resume**

EXHIBIT LIST

Intervenor Center for Biological Diversity's Exhibits No. 600- 799.

Doc. No. **Author and title**

Exhibit 600: Testimony of Bill Powers, P.E., Regarding Alternatives, Declaration, Resume.

Exhibit 601: Renewable Energy World, Germany Adds Nearly 1% of Electricity Supply with Solar in Eight Months, October 4, 2010.

Exhibit 602: CPUC Press Release – Docket A.08-03-015, *CPUC Approves Edison Solar Roof Program*, June 18, 2009. "The energy generated from the project will be used to serve Edison's retail customers and the output from these facilities will be counted towards Edison's RPS goals."

Exhibit 603: CPUC Resolution E-4240, *Approval of a power purchase agreement (PPA) for generation from a new solar photovoltaic facility between PG&E and El Dorado Energy*, LLC (Sempra Generation), May 18, 2009.

Exhibit 604: GreenTech Media, Sempra Wants 300 MW Plus of Solar in Arizona, April 22, 2009. "The electricity we are getting out of the 10-megawatt is the lowest cost solar energy ever generated from anywhere in the world." (CEO Michael Allman).

Exhibit 605: First Solar press release, First Solar Sells California Solar Power Project to NRG, November 23, 2009.

Exhibit 606: SCE Application A.08-03-015, Solar Photovoltaic (PV) Program Application, March 27, 2008,

Exhibit 607: CPUC Press Release – Docket A.09-02-019, CPUC Approves Solar PV Program for PG&E, April 22, 2010.

Exhibit 608: CPUC Rulemaking R.08-08-009 – California RPS Program, Administrative Law Judge's Ruling on Additional Commission Consideration of a Feed-In Tariff, Attachment A - Energy Division FIT Staff Proposal, March 27, 2009, p. 15.

Exhibit 609: E-mail from M. Martyak, PowerSecure (www.powersecure.com), to B. Powers, Powers Engineering, January 13, 2010. Approximate cost to upgrade older 100 MW distribution substation to full bidirectional flow, assuming four 25 MW load banks with four circuit breakers each (16 total), would be $400,000 to $450,000.

Exhibit 610: CPUC Application No. 06-08-010, Matter of the Application of San Diego Gas & Electric Company (U-902-E) for a Certificate of Public Convenience and Necessity for the Sunrise Powerlink Transmission Project, Chapter 5: Prepared Rebuttal Testimony of SDG&E in Response to Phase 2 Testimony of Powers Engineering, March 28, 2008, p. 5.20.

Exhibit 611: E3 and Black & Veatch, Straw proposal of solution to address short-term problem of information gap, presentation at CPUC Re-DEC Working Group Meeting, December 9, 2009, p. 9. Online at: http://www.cpuc.ca.gov/PUC/energy/Renewables/Re-DEC.htm

Exhibit 612: New York Times, Climate Change Seen as Threat to U.S. Security, August 9, 2009.

Exhibit 613: CPUC PG&E Application A.09-02-019, Application of Pacific Gas and Electric Company to Implement Its Photovoltaic Program, February 24, 2009.

Exhibit 614: E3 and Black & Veatch, Summary of PV Potential Assessment in RETI and the 33% Implementation Analysis, presentation at Re-DEC Working Group Meeting, December 9, 2009, p. 24. Online at: http://www.cpuc.ca.gov/PUC/energy/Renewables/Re-DEC.htm

Exhibit 615: CPUC, 33% Renewables Portfolio Standard Implementation Analysis Preliminary Results, June 2009

Exhibit 616: Navigant, PV Grid Connected Market Potential under a Cost Breakthrough Scenario, prepared for The Energy Foundation, September 2004, p. 83. California commercial rooftop PV potential estimated at approximately 37,000 MWp.

Exhibit 617: RightCycle Inc. comment letter, working group member response to June 2009 33% Renewables Portfolio Standard Implementation Analysis Preliminary Results, in response to CPUC request for comments, August 28, 2009.

Exhibit 618: J. Firooz, P.E., CAISO: How Its Transmission Planning Process has Lost Sight of the Public's Interest, April 2010.

Exhibit 619: DOE, DOE Solar Vision Study – DRAFT, May 28, 2010,

Exhibit 620: CPUC Resolution E-4214, 2008 Market Price Referent values for use in the 2008 Renewable Portfolio Standard solicitations, December 18, 2008. MPR, 2012 operational date, 20-yr PPA: $0.12126/kWh.

Exhibit 621: SCE Application A.08-03-015, Solar Photovoltaic (PV) Program Supplemental Rebuttal Testimony, October 14, 2008

Exhibit 622: CPUC Rulemaking R.06-02-012, Develop Additional Methods to Implement California RPS Program, Pre-Workshop Comments of

GreenVolts, Cleantech America, and Community Environmental Council on the 2008 Market Price Referent, March 6, 2008, p. 15.

Exhibit 623: SNL Financial, SoCalEd orders 200 MW of solar panels, plans solicitation for 250 MW more, March 10, 2010

Exhibit 624: SCE Application A.08-03-015, Solar Photovoltaic (PV) Program Testimony, March 27, 2008, p. 32.

Exhibit 625: SNL Financial, SoCalEd taps Trina Solar to supply 45 MW of PV modules, June 9, 2010.

Exhibit 626: Worldwatch Institute, Record Growth in Photovoltaic Capacity and Momentum Builds for Concentrating Solar Power, June 3, 2010

Exhibit 627: Schreiber, D. - EuPD Research, PV Thin-film Markets, Manufacturers, Margins, presentation at 1st Thin-Film Summit, San Francisco, December 1-2, 2008. Exhibit 829 Genesis

Exhibit 628: First Solar press release, First Solar Becomes First PV Company to Produce 1GW in a Single Year, December 15, 2009.

Exhibit 629: B. Murphy – Fulcrum Technologies, Inc., The Power and Potential of CdTe (thin-film) PV, presented at 2nd Thin-Film Summit, San Francisco, December 1-2, 2009.

Exhibit 630: PV Tech, Worldwide photovoltaics installations grew 110% in 2008, says Solarbuzz, March 16, 2009.

Exhibit 631: PV Tech, German market booming: Inverter and module supplies running out at Phoenix Solar, November 15, 2009.

Exhibit 632: Renewable Energy World, Germany Adds Nearly 1% of Electricity Supply with Solar in Eight Months, October 4, 2010

Exhibit 633: Chadbourne & Parke Project Finance Newswire, Germany Cuts Solar Subsidy, April 2010.

Exhibit 634: RETI discussion draft, RETI Net Short Update - Evaluating the Need for Expanded Electric Transmission Capacity for Renewable Energy, February 22, 2010.

Exhibit 635: U.S. DOE, Stand-Alone Flat-plate Photovoltaic Systems: System Sizing and Life-Cycle Costing Methodology for Federal Agencies, 1984, Appendix, p. A-27. ** to be provided**

Exhibit 636: NREL, Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors, California cities data: http://rredc.nrel.gov/solar/pubs/redbook/PDFs/CA.PDF ** to be provided**

Exhibit 637: E-mail communication between Don Kondoleon, manager - CEC Transmission Evaluation Program, and Bill Powers of Powers Engineering, January 30, 2008 [Exhibit 23 EITP]

Exhibit 638: Transmission & Distribution World, California bulks up to provide more transmission capacity, June 1, 2004 [Exhibit 12 EITP]

Exhibit 639: Anthem Group press release, Central California Renewable Master Plan, March 2010.

Exhibit 640: Testimony of Ileene Anderson Re: Impacts to Sensitive Plants and Wildlife from the Proposed Palen Solar Energy Project, Declaration, and Resume

Exhibit 641: Moilanen, A., A.J.A. van Teeffelen, Y. Ben-Haim and S. Ferrier. 2009. How much compensation is enough? A framework for incorporating uncertainty and time discounting when calculating offset ratios for impacted habitat. Restoration Ecology 17(4): 470-478.

Exhibit 642: Norton, D.A. 2009. Biodiversity offsets: two New Zealand case studies and an assessment framework. Environmental Management 43(4):698-706

Exhibit 643: U.S. Fish and Wildlife Service (USFWS) 2009. Range-wide monitoring of the Mojave population of the Desert Tortoise: 2007 Annual Report. Report by the Desert Tortoise Recovery Office, U.S. Fish and Wildlife Service, Reno, Nevada. Pgs. 77

Exhibit 644: Gowan, T. and K.H. Berry. 2009. Progress Report for 2009: The Health Status of Translocated Desert Tortoises (Gopherus agassizii) in the Fort Irwin Translocation Area and Surrounding Release Plots, San Bernardino County, California: Year 2. for National Training Center Fort Irwin. Pgs. 27.

Exhibit 645: Independent Science Advisors (ISA) 2010. Recommendations of Independent Science Advisors for the California Desert Renewable Energy Conservation Plan (DRECP). Prepared For Renewable Energy Action Team. Prepared By The DRECP Independent Science Advisors. DRECP-1000-2010-008. August 2010. Pgs. 172

Exhibit 646: USFWS 2010. Translocation of desert tortoises (Mojave population) from project development sites: Plan development guidance. U.S. Fish and Wildlife Service. August 2010. Pgs. 11 Available at http://www.fws.gov/ventura/speciesinfo/protocols_guidelines/

Exhibit 647: BLM 2002. NECO map 2-21. In Appendix A of Northern and Eastern Colorado Plan.

Exhibit 648: USFWS 1994. Desert tortoise (Mojave population) Recovery Plan. U.S. Fish and Wildlife Service, Portland, Oregon. 73 pages plus appendices.

Exhibit 649: Murphy, R.W., K.H. Berry, T. Edwards and A.M. McLuckie. 2007. A genetic assessment of the recovery units for the Mojave population of the desert tortoise, *Gopherus agassizii*. Chelonian Conservation 6(2): 229-251.

Exhibit 650: Barrows, C.W. 1997. Habitat relationships of the Coachella Valley fringe-toed lizard (Uma inornata). Southwestern Naturalist 42(2): 218-223.

Exhibit 651: Esque, T.C., K.E. Nussear, K.K. Drake, A.D. Walde, K.H. Berry, R.C. Averill-Murray, A. Peter Woodman, W.I. Boarman, P.A. Medica, J. Mack and J.S. Heaton. 2010. Effects of subsidized predators, resource variability and human population density on the desert tortoise populations in the Mojave desert, USA. Endangered Species Research 12: 167-177.

Exhibit 652: McCrary, M.D. 1986. Avian Mortality at a Solar Energy Power Plant. Journal of Field Ornithology 57(2): 135-141

Exhibit 653: Klem, D. 1990. Collisions Between Birds and Windows: Mortality and Prevention. Journal of Field Ornithology 61(1): 120-128.

Exhibit 654: Erickson, W.P., G. D Johnson, and D.P. Young, Jr. 2005. A Summary and Comparison of Bird Mortality form Anthropogenic Causes with an Emphasis on Collisions. USDA Forest Service Gen. Tech. Rep. PSW-GTR-191. pgs. 1029-1042

Exhibit 655: Wilkerson R.L. and R.B. Siegel. 2010. Assessing changes in the distribution and abundance of burrowing owls in California, 1993-2007. Bird Populations 10: 1-36.

Exhibit 656: Institute for Bird Populations (IBP) 2008. Breeding Burrowing Owl Survey Newsletter, Spring 2008. pgs.4.

Exhibit 657: Manning, J.A. 2009. Burrowing owl population size in the Imperial Valley, California: survey and sampling methodologies for estimation.

Final report to the Imperial Irrigation District, Imperial, California, USA, April 15, 2009. Pgs 193.

Exhibit 658: USFWS 2003. Status Assessment and Conservation Plan for the Western Burrowing Owl in the United States. Biological Technical Publication BTP-R6001-2003. Pgs 120.

Exhibit 659: Dunn, R.R. 2005. Modern Insect Extinctions, the Neglected Majority. Conservation Biology 19 (4): 1030-1036.

Exhibit 660: Belnap, J. 2006. The potential roles of biological soil crusts in dryland hydrologic cycles. Hydrologic Processes 20: 3159-3178.

Exhibit 661: Belnap, J. 2001. Biological Soil Crusts and Wind Erosion. Chapter 25 in Ecological Studies Vol. 150. J. Belnap and O.L. Lange (eds.) Biological soil crusts: structure, function and Management. Springer-Verlag, Berlin Heidelberg. Pgs. 9.

Exhibit 662: Belnap, J. and D. Eldridge 2001. Distrurbance and Recovery of Biological Soil Crusts. Chapter 27 in Ecological Studies Vol. 150. J. Belnap and O.L. Lange (eds.) Biological soil crusts: structure, function and Management. Springer-Verlag, Berlin Heidelberg. Pgs. 21.

Exhibit 663: Brown, D.E. and R.A. Minnich. 1986. Fire and Changes in Creosote Bush Scrub of the Western Sonoran Desert, CA. American Midland Naturalist 116(2): 411-422.

Exhibit 664: Lovich, J. E. and D. Bainbridge 1999. Anthropogenic Degradation of the Southern California Desert Ecosystem and Prospects for Natural Recovery and Restoration. Environmental Management 24(3): 309-326.

Exhibit 665: Brooks, M.L. 2000. Competition Between Alien Annual Grasses and Native Annual Plants in the Mojave Desert. American Midland Naturalist 144: 92-108.

Exhibit 666: Brooks, M. L. and J. V. Draper. 2006. Fire effects on seed banks and vegetation in the Eastern Mojave Desert: implications for post-fire management, extended abstract, U.S. Geological Survey, Western Ecological Research Center, Henderson, Nevada, 3 p.

Exhibit 667: Brooks, M.L. and R.A. Minnich. 2007. Fire in the Southeastern Deserts Bioregion. Chp 16 in: Sugihara, N.G., J.W. van Wagtendonk, J. Fites-Kaufman, K.E. Shaffer, and A.E. Thode (eds.). Fire in California Ecosystems. University of California Press, Berkeley.

Exhibit 667: Dutcher, K. E. 2009. The effects of wildfire on reptile populations in the Mojave National Preserve, California. Final Report to the National Park Service, California State University, Long Beach. Pgs 28.

Additional Documents Cited in Testimony: Official Notice Requested

Energy Action Plan I: http://www.energy.ca.gov/energy_action_plan/2003-05-08_ACTION_PLAN.PDF

Energy Action Plan II: http://www.energy.ca.gov/energy_action_plan/2005-09-21_EAP2_FINAL.PDF

CEC, *2009 Integrated Energy Policy Report (IEPR) – Final Committee Report*, December 2009. http://www.energy.ca.gov/2009publications/CEC-100-2009-003/CEC-100-2009-003-CMF.PDF

CEC, *2007 Integrated Energy Policy Report*, December 2007 http://www.energy.ca.gov/2007publications/CEC-100-2007-008/CEC-100-2007-008-CMF.PDF

CEC, Large Solar Energy Projects webpage: http://www.energy.ca.gov/siting/solar/index.html

CALIFORNIA ROOFTOP PHOTOVOLTAIC (PV) RESOURCE ASSESSMENT AND GROWTH POTENTIAL BY COUNTY, Navigant for CEC, September 2007 CEC-500-2007-048 http://www.energy.ca.gov/2007publications/CEC-500-2007-048/CEC-500-2007-048.PDF

RETI, *Phase 1A Final Report*, August 2008, Appendix B, http://www.energy.ca.gov/2008publications/RETI-1000-2008-002/RETI-1000-2008-002-F.PDF

Renewable Energy Transmission Initiative, *RETI Phase 1B Final Report*, January 2009, http://www.energy.ca.gov/2008publications/RETI-1000-2008-003/RETI-1000-2008-003-F.PDF

RETI, *Phase 2B Final Report*, May 2010, http://www.energy.ca.gov/2010publications/RETI-1000-2010-002/RETI-1000-2010-002-F.PDF

CEC, Chula Vista Energy Upgrade Project - Application for Certification (07-AFC-4) San Diego County, *Final Commission Decision*, June 2009. http://www.energy.ca.gov/2009publications/CEC-800-2009-001/CEC-800-2009-001-CMF.PDF

CEC, *Strategic Transmission Investment Plan*, November 2005,
http://www.energy.ca.gov/2005publications/CEC-100-2005-006/CEC-100-2005-006-CTD.PDF

Respectfully submitted,

Date: October 6, 2010

Ileene Anderson
Public Lands Desert Director
Center for Biological Diversity
PMB 447, 8033 Sunset Boulevard
Los Angeles, CA 90046
(323) 654-5943
ianderson@biologicaldiversity.org

Lisa T. Belenky, Senior Attorney
Center for Biological Diversity
351 California St., Suite 600
San Francisco, CA 94104
Direct: 415-632-5307
Fax: 415-436-9683
lbelenky@biologicaldiversity.org

STATE OF CALIFORNIA

Energy Resources Conservation and Development Commission

In the Matter of:	
APPLICATION FOR CERTIFICATION FOR THE PSPP SOLAR POWER PLANT	DOCKET NO. 09-AFC-7

THE CENTER FOR BIOLOGICAL DIVERSITY

OPENING TESTIMONY

TESTIMONY OF BILL POWERS, P.E.

October 5, 2010

Lisa T. Belenky, Senior Attorney
Center for Biological Diversity
351 California St., Suite 600
San Francisco, CA 94104
Direct: 415-632-5307
Fax: 415-436-9683
lbelenky@biologicaldiversity.org

Ileene Anderson
Public Lands Desert Director
Center for Biological Diversity
PMB 447, 8033 Sunset Boulevard
Los Angeles, CA 90046
(323) 654-5943
ianderson@biologicaldiversity.org

I. Introduction

My testimony addresses: 1) the inadequate analysis of the distributed photovoltaic (PV) alternative to the proposed Palen Solar Power Plant (PSPP) in the Revised Staff Analysis (RSA), and 2) the proposed Westlands Water District Competitive Renewable Energy Zone, located on retired farmland in the Central Valley and served by 5,000 MW of existing transmission capacity, as a superior alternative location for central station solar projects like PSPP.

I am a registered professional mechanical engineer in California with over 25 years of experience in the energy and environmental fields. I have permitted five 50 MW peaking turbine installations in California, as well as numerous gas turbine, microturbine, and engine cogeneration plants around the state. I organized conferences on permitting gas turbine power plants (2001) and dry cooling systems for power plants (2002) as chair of the San Diego Chapter of the Air & Waste Management Association. I am the author of the October 2007 strategic energy plan for the San Diego region titled "San Diego Smart Energy 2020." The plan uses the state's Energy Action Plan as the framework for accelerated introduction of local renewable and cogeneration distributed resources to reduce greenhouse gas emissions from power generation in the San Diego region by 50 percent by 2020. I am the author of several 2009 articles in Natural Gas & Electricity Journal on use of large-scale distributed solar PV in urban areas as a cost-effective substitute for new gas turbine peaking capacity.

II. Rooftop PV Is at the Top of the Energy Action Plan Loading Order

The March 2010 RSA states, in discussing the conservation and demand-side management alternative to PSPP, that cost-effective energy efficiency is the resource of first choice in meeting California's energy needs (p. B.2-80):

> "Conservation and demand-side management consist of a variety of approaches to reduce of electricity use, including energy efficiency and conservation, building and appliance standards, and load management and fuel substitution. In 2005 the Energy Commission and CPUC's Energy Action Plan II declared cost effective energy efficiency as the resource of first choice for meeting California's energy needs."

The CEC and the CPUC developed the "Energy Action Plan" in 2003 to guide strategic energy decisionmaking in California. The Energy Action Plan establishes the energy resource "loading order," or priority list that defines how California's energy needs are to be met. Energy Action Plan I was published in May 2003.[1] Energy Action Plan I describes the loading order in the following manner (p. 4):

> "The Action Plan envisions a "loading order" of energy resources that will guide decisions made by the agencies jointly and singly. First, the agencies want to optimize all strategies for increasing conservation and energy efficiency to minimize increases in electricity and natural gas demand. Second, recognizing that new generation is both necessary and desirable, the agencies would like to see these needs met first by renewable energy resources and distributed generation. Third, because the preferred resources require both sufficient investment and adequate time to "get to scale," the agencies also will support additional clean, fossil fuel,

[1] Energy Action Plan I: http://www.energy.ca.gov/energy_action_plan/2003-05-08_ACTION_PLAN.PDF

central-station generation. Simultaneously, the agencies intend to improve the bulk electricity transmission grid and distribution facility infrastructure to support growing demand centers and the interconnection of new generation."

Energy Action Plan I, Under "Optimize Energy Conservation and Resource Efficiency," states (p. 5):

> "Incorporate distributed generation or renewable technologies into energy efficiency standards for new building construction."

Energy Action Plan I identifies rooftop PV as a de facto energy efficiency measure with this statement. As noted in the PSPP March 2010 RSA (p. B.2-80), energy efficiency is at the top of the loading order. Energy Action Plan I also states, Under "Promote Customer and Utility-Owned Distributed Generation," (p. 7):

> "Distributed generation is an important local resource that can enhance reliability and provide high quality power, without compromising environmental quality. The state is promoting and encouraging clean and renewable customer and utility owned distributed generation as a key component of its energy system. Clean distributed generation should enhance the state's environmental goals. This determined and aggressive commitment to efficient, clean and renewable energy resources will provide vision and leadership to others seeking to enhance environmental quality and moderate energy sector impacts on climate change. Such resources, by their characteristics, are virtually guaranteed to serve California load. With proper inducements distributed generation will become economic.
>
> - Promote clean, small generation resources located at load centers.
> - Determine system benefits of distributed generation and related costs.
> - Develop standards so that renewable distributed generation may participate in the Renewable Portfolio Standard program."

Energy Action Plan I prioritizes rooftop PV as the preferable renewable resource, but indicates obliquely that it is costly and that in any case distributed PV is not eligible to participate in the Renewable Portfolio Standard (RPS) program. Therefore investor-owned utilities have no incentive to develop distributed PV resources. Since Energy Action Plan I was approved in 2003, PV cost has dropped dramatically. Commercial distributed PV is half the cost it was in 2003 and costs continue to drop. Residential PV is following quickly behind. Distributed PV is also now eligible for the RPS program.[2]

Energy Action Plan II was adopted in September 2005.[3] The purpose of Energy Action Plan II is stated as (p. 1): "EAP II is intended to look forward to the actions needed in California over the next few years, and to refine and strengthen the foundation prepared by EAP I." Energy Action Plan II reaffirms the loading order stating (p. 2):

> "EAP II continues the strong support for the loading order – endorsed by Governor Schwarzenegger – that describes the priority sequence for actions to address increasing energy needs. The loading order identifies energy efficiency and demand response as the

[2] CPUC Press Release – Docket A.08-03-015, *CPUC Approves Edison Solar Roof Program*, June 18, 2009. "The energy generated from the project will be used to serve Edison's retail customers and the output from these facilities will be counted towards Edison's RPS goals."

[3] Energy Action Plan II: http://www.energy.ca.gov/energy_action_plan/2005-09-21_EAP2_FINAL.PDF

State's preferred means of meeting growing energy needs. After cost-effective efficiency and demand response, we rely on renewable sources of power and distributed generation, such as combined heat and power applications. To the extent efficiency, demand response, renewable resources, and distributed generation are unable to satisfy increasing energy and capacity needs, we support clean and efficient fossil-fired generation."

The CEC's *2009 Integrated Energy Policy Report (IEPR) – Final Committee Report* (December 2009), underscores the integration of building PV as a critical component of "net zero" energy use targets for new residential and commercial construction, under the heading "Energy Efficiency and the Environment," explaining:[4]

> "With the focus on reducing GHG emissions in the electricity sector, energy efficiency takes center stage as a zero emissions strategy. One of the primary strategies to reduce GHG emissions through energy efficiency is the concept of zero net energy buildings. In the 2007 IEPR, the Energy Commission recommended increasing the efficiency standards for buildings so that, when combined with on-site generation, newly constructed buildings could be zero net energy by 2020 for residences and by 2030 for commercial buildings.
>
> A zero net energy building merges highly energy efficient building construction and state-of-the-art appliances and lighting systems to reduce a building's load and peak requirements and includes on-site renewable energy such as solar PV to meet remaining energy needs. The result is a grid-connected building that draws energy from, and feeds surplus energy to, the grid. The goal is for the building to use net zero energy over the year."

The PSPP March 2010 RSA acknowledges the state's commitment to net zero residential and commercial buildings, stating (p. B.2-81):

> "The CPUC, with support from the Governor's Office, the Energy Commission, and the California Air Resources Board, among others, adopted the California Long-Term Energy Efficiency Strategy Plan for 2009 to 2020 in September 2008 (CPUC 2008). The plan is a framework for all sectors in California including industry, agriculture, large and small businesses, and households. Major goals of the plan include:
>
> - All new residential construction will be zero net energy by 2020;
> - All new commercial construction will be zero net energy by 2030;
> - Heating, ventilation, and air conditioning industries will be re-shaped to deliver maximum performance systems;
> - Eligible low-income customers will be able to participate in the Low Income Energy Efficiency program and will be provided with cost-effective energy efficiency measures in their residences by 2020."

The RSA is flawed in its failure to identify rooftop PV as a higher priority in the Energy Action Plan loading order, and California's long-term energy efficiency strategy plan, than utility-scale remote solar resources like PSPP. Rooftop (or parking lot) distributed PV is an integral component of the long-term energy efficiency strategy plan adopted by the CPUC in 2008. Rooftop solar can be added rapidly. Germany added 4,900 MW of primarily rooftop PV in the first eight months of 2010.[5] This is equivalent to one 500 MW PSPP every month.

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[4] CEC, *2009 Integrated Energy Policy Report (IEPR) – Final Committee Report*, December 2009, p. 56.

[5] Renewable Energy World, *Germany Adds Nearly 1% of Electricity Supply with Solar in Eight*

Energy Action Plan II declares cost-effective energy efficiency as the resource of first choice for meeting California's energy needs. The CEC rejection of distributed PV as a superior alternative to the proposed PSPP solar thermal projects ignores the integral role of distributed PV in the CEC's own definition of energy efficiency and net zero buildings in the 2009 IEPR.

III. RSA Rationale for Eliminating Rooftop PV is Flawed

The March 2010 RSA correctly describes that a distributed rooftop PV alternative has essentially no environmental impact, stating (p. B.2-64):

- Distributed solar PV is assumed to be located on already existing structures or disturbed areas so little to no new ground disturbance would be required and there would be few associated biological impacts.
- Relatively minimal maintenance and washing of the solar panels would be required.
- Because most PV panels are black to absorb sun, rather than mirrored to reflect it, glare would be minimal relative to reflective technologies (like PSPP).
- Additionally, the distributed solar PV alternative would not require the additional operational components, such as dry-cooling towers, substations, transmission interconnection, maintenance and operation facilities with corresponding visual impacts.

The RSA then eliminates distributed PV, citing a number of reasons why achieving 500 MW of distributed PV is not a feasible substitute for PSPP (RSA, pp. B.2-64, B.2-65):

- Would require accelerated deployment of distributed PV at more than double the historic rate of deployment under the California Solar Initiative.
- Would require lower PV cost - distributed PV is higher cost than central station solar thermal.
- Integrating large amounts of distributed PV on distribution systems throughout California presents challenges – will require development of a new transparent distribution planning framework.

Each of these justifications for elimination of distributed PV is flawed, as explained in the following paragraphs.

A. Distributed PV Is Already Being Deployed at a Much Faster Rate in California than Central Station Solar Thermal

The RSA notes that more than 500 MW of distributed PV was in operation in California through May 2009, and that the PV installation rate doubled between 2008 and 2007 (p. B-62). California has approximately 360 MW of installed solar thermal capacity as of June 2010. With the exception of the 5 MW eSolar power tower demonstration project that came online in 2009 (p. B.2-63), all of this solar thermal capacity was installed between 1984 and 1990.[6]

Months, October 4, 2010. 4,900 MWdc is equivalent to approximately 4,000 MWac at a dc-to-ac conversion factor of 0.82. 4,000 MWac/8 months = 500 MWac/month.

[6] CEC, Large Solar Energy Projects webpage: http://www.energy.ca.gov/siting/solar/index.html

The RSA correctly describes that both SCE and PG&E, the two largest investor-owned utilities (IOU) in California, are constructing large distributed PV projects (p. B.2-62). SDG&E has a 100 MW distributed PV project in development. The 500 MW SCE urban PV project was approved by the CPUC in June 2009. The 500 MW PG&E distributed PV project was approved by the CPUC in April 2010. These projects are RPS-eligible and will consist of a 250 MW IOU-owned component and a 250 MW third-party component. The power purchase agreement (PPA) between PSPP and SCE is same type of contract mechanism that is being used by SCE to contract for the 250 MW third-party component of its distributed PV project.

Progress in distributed PV installation rates under the California Solar Initiative (CSI) program provides no insight into the ability of the solar industry to carry-out multiple large-scale distributed PV projects simultaneously, in the range of 250 to 500 MW each, in California. The CSI program is not the vehicle that will be used to build these projects. These projects will be built under long-term PPAs between the distributed PV project developer and a utility within the framework of the RPS program.

An example is the PPA between PG&E and Sempra Generation for 10 MW of fixed thin-film PV in Nevada.[7] Sempra Generation is constructing an additional 48 MW of thin-film PV at the Nevada site that will also be under contract to PG&E (p. B.2-60). Sempra Resources is the holding company that owns both Sempra Generation and SDG&E. The PG&E/Sempra PPA is a technology-differentiated renewable energy contract at a price incrementally higher than the market price referent (MPR) to assure that the project developer, Sempra Generation, makes a reasonable return on its investment. The contract is in effect the equivalent of a technology differentiated feed-in tariff for solar power. No incentives beyond the federal investment tax credit and accelerated depreciation available to any solar energy project were necessary. No incentives beyond those already available would be necessary to build 500 MW of distributed PV under a long-term PPA to substitute for PSPP.

Sempra Generation touts the cost of power generated by its 10 MW PV installation in Nevada as "the lowest cost solar energy in the world."[8] The company specifically mentions solar thermal projects like PSPP as producing higher-cost solar energy, stating:[9]

> "Sempra has also evaluated solar thermal power technologies, which use a field of mirrors to concentrate the sunlight to produce heat for electricity generation. The company has found that using solar panels is the cheaper option, (CEO) Allman said. He noted that some of the solar thermal power technologies, such as the use of a central tower for harvesting the heat and generating steam, have yet to be proven commercially."

SCE has a similar RPS-eligible PPA with NRG for the output of a 21 MW fixed thin-film PV array in Blythe, California.[10] This project began operation in December 2009 (p. B.2-60).

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[7] CPUC Resolution E-4240, *Approval of a power purchase agreement (PPA) for generation from a new solar photovoltaic facility between PG&E and El Dorado Energy*, LLC (Sempra Generation), May 18, 2009.
[8] GreenTech Media, *Sempra Wants 300 MW Plus of Solar in Arizona*, April 22, 2009. "The electricity we are getting out of the 10-megawatt is the lowest cost solar energy ever generated from anywhere in the world." (CEO Michael Allman).
[9] Ibid.
[10] First Solar press release, *First Solar Sells California Solar Power Project to NRG*, November 23, 2009.

B. IOUs and California's Energy Policy Makers Acknowledge the Obvious Benefits of Large-Scale Distributed PV Projects as a Direct Complement/Substitute for Remote Central Station Renewable Energy and Associated Transmission

SCE expressed confidence in its March 2008 application to the CPUC for a 250 to 500 MW urban PV project that it can absorb thousands of MW of distributed PV without additional distribution substation infrastructure, stating "SCE's Solar PV Program is targeted at the vast untapped resource of commercial and industrial rooftop space in SCE's service territory"[11] and "SCE has identified numerous potential (rooftop) leasing partners whose portfolios contain several times the amount of roof space needed for even the 500 MW program."[12]

SCE stated it has the ability to balance loads at the distribution substation level to avoid having to add additional distribution infrastructure to handle this large influx of distributed PV power.[13] SCE explains:

> "SCE can coordinate the Solar PV Program with customer demand shifting using existing SCE demand reduction programs on the same circuit. This will create more fully utilized distribution circuit assets. Without such coordination, much more distribution equipment may be needed to increase solar PV deployment. SCE is uniquely situated to combine solar PV Program generation, customer demand programs, and advanced distribution circuit design and operation into one unified system. This is more cost-effective than separate and uncoordinated deployment of each element on separate circuits."[14]

SCE also notes that it will be able to remotely control the output from individual PV arrays to prevent overloading distribution substations or affecting grid reliability:[15]

> "The inverter can be configured with custom software to be remotely controlled. This would allow SCE to change the system output based on circuit loads or weather conditions."

As SCE states, "Because these installations will interconnect at the distribution level, they can be brought on line relatively quickly without the need to plan, permit, and construct the transmission lines."[16] This statement was repeated and expanded in the CPUC's June 18, 2009 press release regarding its approval of the 500 MW SCE urban PV project:[17]

> Added Commissioner John A. Bohn, author of the decision, "This decision is a major step forward in diversifying the mix of renewable resources in California and spurring the development of a new market niche for large scale rooftop solar applications. Unlike other generation resources, these projects can get built quickly and without the need for expensive new transmission lines. And since they are built on existing structures, these projects are extremely benign from an environmental standpoint, with neither land use, water, or air emission impacts. By authorizing both utility-owned and private development of these projects we hope to get the best from both types of ownership structures, promoting competition as well as fostering the rapid development of this nascent market."

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[11] SCE Application A.08-03-015, *Solar Photovoltaic (PV) Program Application*, March 27, 2008, p. 6.
[12] SCE Application A.08-03-015, *Solar Photovoltaic (PV) Program Testimony*, March 27, 2008, p. 44.
[13] SCE Application A.08-03-015, *Solar Photovoltaic (PV) Program Application*, March 27, 2008, pp. 8-9.
[14] Ibid, p. 9.
[15] SCE Application A.08-03-015, *Solar Photovoltaic (PV) Program Testimony*, March 27, 2008, p. 27.
[16] Ibid, p. 6.
[17] CPUC Press Release – Docket A.08-03-015, *CPUC Approves Edison Solar Roof Program*, June 18, 2009.

The CPUC made a similar observation with its approval of the PG&E 500 MW distributed PV project in April 2010:[18]

> "This solar development program has many benefits and can help the state meet its aggressive renewable power goals," said CPUC President Michael R. Peevey. "Smaller scale projects can avoid many of the pitfalls that have plagued larger renewable projects in California, including permitting and transmission challenges. Because of this, programs targeting these resources can serve as a valuable complement to the existing Renewables Portfolio Standard program."

The use of the term "smaller scale" in the CPUC press release is a misnomer. Clearly a 500 MW distributed PV project is the same size as the 500 MW PSPP solar thermal project. Individual rooftop PV arrays in a large distributed PV project are functionally equivalent to single rows of reflective mirrors in a solar thermal project. Each rooftop or row is a small contributor to a much bigger whole.

C. IOUs Need Only Provide a Basic Level of Existing Information on Individual IOU Substation Capacities to PV Developers to Interconnect Over 13,000 MW of Distributed PV with Minimal Interconnection Cost

The CPUC has also calculated, for the entire inventory of approximately 1,700 existing IOU substations, the amount of distributed PV that could be accommodated with minimal interconnection cost based on the following reasoning:[19]

> "Rule 21 specifies maximum generator size relative to the peak load on the load at the point of interconnection at 15%. So, for example, if a generator is interconnected on the low side of a distribution substation bank with a peak load of 20 MW, the maximum Rule 21 interconnection criteria would allow a 3 MW system (3 MW = 15% * 20 MW).
>
> However, the 15% criterion, which is established for all generators regardless of type, was adjusted to 30% for the purposes of determining the technical potential of PV. The 15% limit is established at a level where it is unlikely the generator would have a greater output than the load at the line segment, even in the lowest load hours in the off-peak hours and seasons (such as the middle of the night and in the spring). Since the peak output for photovoltaics is during the middle of the day, PV is unlikely to have any output when loads are lowest. Therefore, a 30% criterion was used for technical interconnection potential estimates. The discussion was held with utility distribution engineers, however, we did not consider formal engineering studies or Rule 21 committee deliberation since the purpose of the analysis was only to define potential."

As a component of the DG FIT development process, the CPUC requested data on peak loads at all IOU substations from the IOUs and compiled that information graphically as shown in Figure

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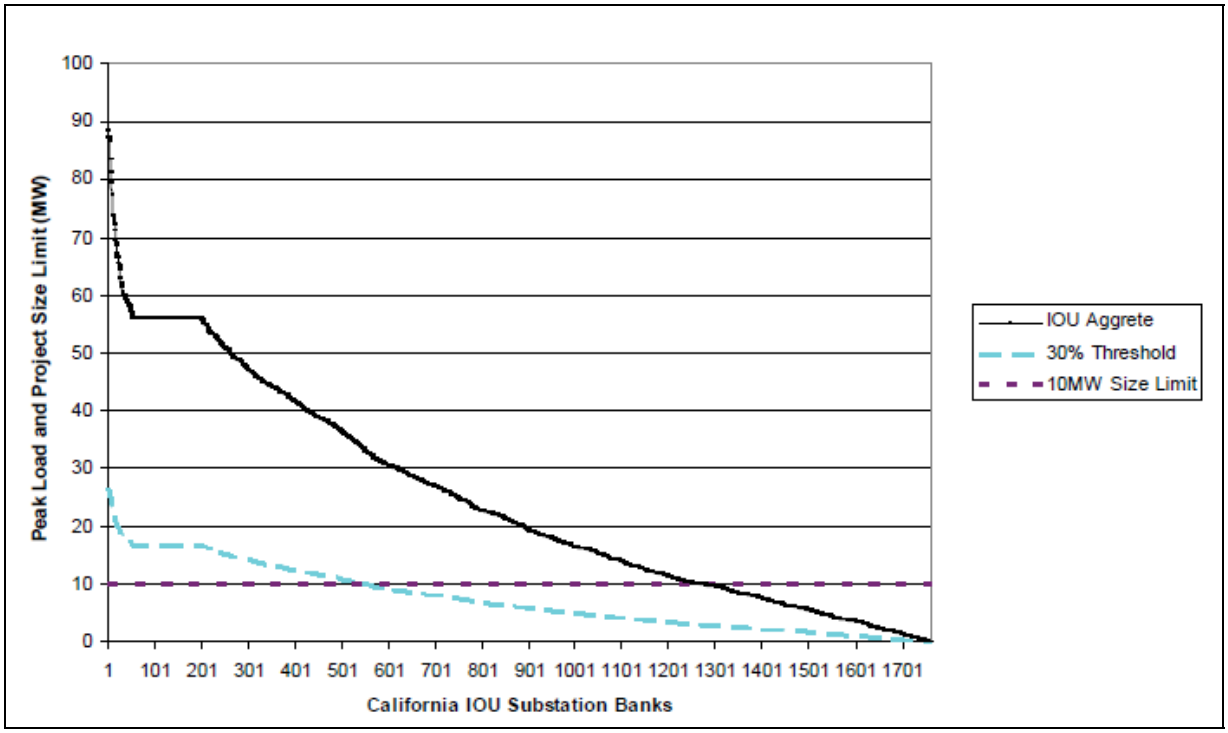
[18] CPUC Press Release – Docket A.09-02-019, *CPUC Approves Solar PV Program for PG&E*, April 22, 2010.
[19] CPUC Rulemaking R.08-08-009 – California RPS Program, Administrative Law Judge's Ruling on Additional Commission Consideration of a Feed-In Tariff, *Attachment A - Energy Division FIT Staff Proposal*, March 27, 2009, p. 15.

1. According to the CPUC, this data was obtained from IOU distribution engineers.[20] I calculate that approximately 13,300 MW of PV can be connected directly to IOU substation load banks based on the data in Figure 1. The supporting calculations for this estimate are provided in Table 1.

The IOUs provide about two-thirds of electric power supplied in California, with publicly-owned utilities like the Los Angeles Department of Water & Power and the Sacramento Municipal Utility District and others providing the rest.[21] Assuming the substation capacity pattern in Figure 1 is also representative of the non-IOU substations, the total California-wide PV that could be interconnected at substation low-side load banks with no substantive substation upgrades would be [13,300/(2/3)] = 19,950 MW.

Figure 1. IOU Substation peak loads, 30% of peak load, and 10 MW reference line



[20] CPUC Rulemaking R.08-08-009 – California RPS Program, Administrative Law Judge's Ruling on Additional Commission Consideration of a Feed-In Tariff, *Attachment A - Energy Division FIT Staff Proposal*, March 27, 2009, pp. 15-16.
[21] CEC, *2007 Integrated Energy Policy Report*, December 2007, Figure 1-11, p. 27.

Table 1. Calculation of distributed PV interconnection capacity to existing IOU substations with minimal interconnection cost from data in Figure 1

Substation range	Number of substations	Calculation of distributed PV that could be interconnected with minimal substation upgrades (MW)	Total distributed PV potential (MW)
1-200	200	average peak ~60 MW x 0.30 = 18 MW	3,600
201-500	300	average peak ~45 MW x 0.30 = 13.5 MW	4,000
501-800	300	average peak ~30 MW x 0.30 = 9 MW	2,700
801-1,000	200	average peak ~20 MW x 0.30 = 6 MW	1,200
1,001-1,600	600	average peak ~10 MW x 0.30 = 3 MW	1,800
		Distributed PV total:	13,300

In sum, approximately 20,000 MW of distributed PV interconnection capacity is available now in California that would require little or no substation upgrading to accommodate the PV.

D. Cost to Upgrade Existing Distribution Substations and Associated Distribution Feeders to Maximize Distributed PV Deployment is Minimal

An upgrade at the substation would be necessary to accommodate the higher power flows in cases where distributed PV, concentrated on clusters of large rooftops, could provide up to 100 percent of a single substation's peak load. A typical 12 kV/69 kV substation can be upgraded to allow two-way (bidirectional) power flows for up to 100 MW of interconnected distributed PV. SDG&E estimates the cost to build a new 12 kV/69 kV substation is $25 million.[22]

The upgrades necessary to allow problem-free bidirectional power flow across an existing substation is far less than the cost of a new substation. The upgrade would consist of retrofitting substation metering and protective equipment from one-way power flow to bidirectional power flow. The cost of such an upgrade for a typical 100 MW distribution substation would be approximately $500,000.[23] This is well under 1 percent of the gross capital cost of 100 MW of state-of-the-art PV at 2010 prices.

Even the cost of a new 100 MW distribution substation, at $25 million, is less than 10 percent of the gross capital cost of 100 MW of state-of-the-art PV at 2010 prices. The substation upgrade cost would be relatively minor compared to the gross capital cost of 100 MW of PV arrays, and would not present a substantive financial hurdle to developing a 100 MW distributed PV resource concentrated in an area served by a single existing substation.

The 2007 IEPR makes clear that incorporating bidirectional capability into distribution substation is a commonsense need in a smart grid environment where higher-and-higher levels of distributed generation are encouraged and expected:[24]

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[22] Ibid, p. 5.21.

[23] E-mail from M. Martyak, PowerSecure (www.powersecure.com), to B. Powers, Powers Engineering, January 13, 2010. Approximate cost to upgrade older 100 MW distribution substation to full bidirectional flow, assuming four 25 MW load banks with four circuit breakers each (16 total), would be $400,000 to $450,000.

[24] CEC, *2007 Integrated Energy Policy Report*, December 2007, pp. 155-156.

> "Utilities spend approximately three-fourths of their total capital budgets on distribution assets, with about two-thirds spent on upgrades and new infrastructure in most years. These investments will remain for 20 to 30 or more years. As utilities throughout the state plan to build new distribution assets and replace old assets, the magnitude of these investments suggests that the state must understand what it is investing in and whether these investments will result in a distribution system that will serve customers in the future. Planning for investment in these assets should include requiring utilities, before undertaking investments in non-advanced grid technologies, to demonstrate that alternative investments in advanced grid technologies that will support grid flexibility have been considered, including from a standpoint of cost effectiveness."

The CPUC assumes that larger PV arrays will be connected directly to the substation low-side (12 kV) load bank. SDG&E estimated that the cost of a 10 MW feeder is $0.6 million per mile.[25] The cost of a 3-mile long dedicated feeder from multiple rooftop PV arrays with a combined capacity of 10 MW to the low-side bus of the substation would be less than $2 million based on SDG&E's cost estimate.

The current capital cost for state-of-the-art commercial rooftop PV is approximately $3,700/kW$_{ac}$. The gross capital cost of 10 MW of rooftop PV at current prices would be $3,700/kW x (1,000 kW/MW) x 10 MW = $37 million. The cost to construct a dedicated feeder to interconnect 10 MW of rooftop PV would be approximately 5 percent of the gross project capital cost. This is a relatively minor cost and represents no financial impediment to developing urban rooftop PV resources.

E. There Is No Security Justification for IOU's Withholding Information on Substation Capacities and Locations from Private PV Developers, and No Economic or Technical Justification for Failure to Incorporate Smart Grid Features in New and Upgraded Distribution Substations

The March 2010 RSA notes that accommodating large quantities of distributed generation PV located at customer sites efficiently and cost-effectively will require the development of a new, transparent distribution planning framework (p. B.2-65). Transparent distribution planning by the IOUs is a reasonable expectation. Lack of transparent distribution planning is not a credible justification by an IOU or the CEC to reject distributed PV as a substitute for PSPP.

The CEC is already on record advocating that IOUs must incorporate smart grid elements, including bidirectional power flow, into new and upgraded distribution substations.[26] It would likely come as a surprise to most California ratepayers that it is not already standard practice for California IOUs to incorporate bidirectional power flow capability into any new distribution substation or major upgrade of an existing substation. As noted, approximately 20,000 MW of distributed PV can flow into California distribution substations without retrofitting these substations for bidirectional power flow. The lack of bidirectional power flow capability on

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[25] Application No. 06-08-010, Matter of the Application of San DiegoGas & Electric Company (U-902-E) for a Certificate of Public Convenience and Necessity for the Sunrise Powerlink Transmission Project, *Chapter 5: Prepared Rebuttal Testimony of SDG&E in Response to Phase 2 Testimony of Powers Engineering*, March 28, 2008, p. 5.20.

[26] CEC, *2007 Integrated Energy Policy Report*, December 2007, pp. 155-156.

California distribution substations is not a short- or mid-term impediment to maximizing distributed PV deployment.

However, at some point over the operational lifetime of a new or upgraded distribution substation it is prudent to assume that failure to equip the substation to accommodate bidirectional power flow will act as an artificial brake on the quantity of distributed PV the substation can accept. Equipping a distribution substation for bidirectional power flow is not expensive, costing in the range of $500,000 for a typical 100 MW distribution substation. Failure of IOUs to incorporate smart grid features as standard elements in new and upgraded distribution substations is not a credible justification by an IOU or the CEC to reject distributed PV as a substitute for PSPP.

The rationale put forth for restricting information to private distributed PV project developers includes "Providing details on distribution system could compromise homeland security" and "Information on peak loads and system configuration may be considered commercially sensitive."[27] There is no sound basis for these two justifications.

In the first instance, climate change is seen as a major threat to national security by the U.S. defense establishment.[28] Withholding information that would allow rapid progress on addressing climate change on homeland security grounds is contrary to the national security interest. Secondly, all IOU expenditures are passed on to customers. The withholding of information on peak loads and system configuration by the IOU to protect unsubstantiated commercial sensitivity concerns, to the extent it prevents the rapid deployment of competitively-bid distributed PV in urban centers at or near the point-of-use, would have a potentially substantial negative impact on ratepayers and slow progress on addressing climate change.

Much of the necessary information is already in the public domain in some form and should be compiled and made available to distributed PV developers in a transparent and efficient format. For example, the CPUC already has the data on IOU substation interconnection limitations as shown in Figure 1. Another example is information on the location of IOU substations. Maps showing the location of all IOU substations are readily available for purchase from the CEC Cartography Unit.

The province of Ontario (Canada) makes publicly-available information on substation location and available capacity to facilitate the development of distributed PV in the province.[29] This same information protocol should be followed by California IOUs.

Finally, SCE must provide this type of information to third-party PV developers for the 250 MW private PV developer set-aside component of its 500 MW urban PV project approved by the CPUC in June 2009.

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[27] E3 and Black & Veatch, *Straw proposal of solution to address short-term problem of information gap*, presentation at CPUC Re-DEC Working Group Meeting, December 9, 2009, p. 9. Online at: http://www.cpuc.ca.gov/PUC/energy/Renewables/Re-DEC.htm

[28] New York Times, *Climate Change Seen as Threat to U.S. Security*, August 9, 2009.

[29] E3 and Black & Veatch, *Straw proposal of solution to address short-term problem of information gap*, presentation at CPUC Re-DEC Working Group Meeting, December 9, 2009, p. 8.

F. There is Sufficient Existing Large Commercial Roof Space in PG&E and SCE Territories to Build at Least Fifteen PSPP Plants

The 2009 IEPR Final Committee Report recognizes the huge technical potential of rooftop distributed PV to meet California's renewable energy targets, stating:[30]

> "Recent studies indicate substantial technical potential for distribution-level generation resources located at or near load. A 2007 estimate from the Energy Commission suggests that there is roof space for over 60,000 MW of PV capacity, although the study did not factor in roof space that is shaded or being used for another purpose."

60,000 MW is approximately the peak summertime load for all of California, and 120 times the 500 MW capacity of PSPP. It is important to note that the 2009 IEPR document is incorrect in asserting the 2007 rooftop PV estimate did not factor in roof shading or other limitations. The 60,000 MW estimate assumes only 24 percent of the rooftop of a typical tilt-roof residential rooftop is available for PV, and only 60 to 65 percent of flat-roof commercial rooftops are available for PV. The rationale for these estimates is explained in the 2007 (Navigant) estimate.[31]

The 60,000 MW rooftop PV estimate by Navigant does not account for any of the distributed PV described in the Renewable Energy Transmission Initiative (RETI) process. RETI is California's ongoing renewable energy transmission siting process. RETI evaluated a distributed PV alternative that would produce 27,500 MWac from 20 MW increments of ground-mounted PV arrays at 1,375 non-urban substations around the state.[32] This is similar to the approach that PG&E is following. Constructing distributed PV arrays around substations is the primary focus of PG&E's 500 MW distributed PV project.[33]

Black & Veatch is the engineering contractor preparing the RETI reports. Energy & Environmental Economics, Inc. (E3) is the engineering contractor that prepared the June 2009 CPUC preliminary analysis of the cost to reach 33 percent renewable energy by 2020. These two firms were contracted by the CPUC to lead the CPUC's renewable distributed generation coalition ("Re-DEC") working group process. The presentation of E3 and Black & Veatch at the December 9, 2009 initial meeting of the Re-DEC Working Group included an estimate of over 8,000 MWac of large commercial roof space in SCE and PG&E service territories in close proximity to existing distribution substations.[34]

Black & Veatch used GIS to identify large roofs in California and count available large roof area. The criteria used to select rooftops included:

- Urban areas with little available land
- Flat roofs larger than ~1/3 acre
- Assume 65 percent usable space on roof
- Within 3 miles of distribution substation

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[30] CEC, *2009 Integrated Energy Policy Report (IEPR) – Final Committee Report*, December 2009, p. 193.
[31] See: http://www.energy.ca.gov/2007publications/CEC-500-2007-048/CEC-500-2007-048.PDF
[32] Renewable Energy Transmission Initiative, *RETI Phase 1B Final Report*, January 2009, p. 6-25.
[33] PG&E Application A.09-02-019, *Application of Pacific Gas and Electric Company to Implement Its Photovoltaic Program*, February 24, 2009.
[34] E3 and Black & Veatch, *Summary of PV Potential Assessment in RETI and the 33% Implementation Analysis*, presentation at Re-DEC Working Group Meeting, December 9, 2009, p. 24. Online at: http://www.cpuc.ca.gov/PUC/energy/Renewables/Re-DEC.htm

The Black & Veatch estimate for PG&E territory is 2,922 MWac. The estimate for SCE territory is 5,243 MWac. This is a combined rooftop PV capacity of over 8,000 MWac. The combined large commercial rooftop capacity is more than 16 times the 500 MW capacity of PSPP.

Large commercial rooftop PV capacity is a subset of the universe of all commercial rooftop capacity, which includes medium and small commercial rooftops as well. A 2004 Navigant study prepared for the Energy Foundation estimated the 2010 commercial rooftop PV capacity in California at approximately 37,000 MWdc.[35] There is a tremendous amount of commercial roof space available for PV.

G. RSA Uses Outdated PV Cost Assumption to Erroneously Assert PSPP is Lower Cost than Equivalent Distributed PV Capacity

There is no justification for the RSA using an obsolete cost assumption to eliminate large-scale distributed PV as an alternative to the PSPP. The RSA relies on the June 2009 CPUC *33% Renewables Portfolio Standard Implementation Analysis Preliminary Results* assertion that the cost of a high distributed PV case is significantly higher than the other 33 percent RPS alternative cases (p. B.2-65). The 33 percent reference case includes 10,000 MW of remote central station solar plants like PSPP. The assertion that the high distributed generation case is significantly higher cost than the reference case was incorrect in June 2009 and is definitively obsolete in June 2010.

The CPUC erroneously assumed a distributed PV cost of over $7/Wac in its June 2009 analysis. However, the CPUC also analyzed a sensitivity case with the capital cost of fixed thin-film PV at $3.70/Wac. The CPUC determined that at $3.70/Wac, the cost of the 33 percent standard remote case and the high DG alternative are similar. RETI has confirmed that the PV pricing cited by the CPUC in its sensitivity analysis is commercially available and not a projection, stating,"Thin film solar PV was previously treated as a sensitivity study, but due to falling costs and the increased prevalence of thin film, it is now being considered as one of the available commercial technologies in addition to tracking crystalline PV."[36]

Accurate PV pricing data has been available from the SCE urban solar PV application for over two years. SCE provided an installed cost of $3.50/Wdc (~$4/Wac) in its March 2008 application to the CPUC to build a 250 to 500 MW urban PV project. RETI states that the commercially available thin-film PV has a capital cost range of $3.60 to $4/Wac, and commercially available single-axis tracking polysilicon PV has a cost range of $4 to $5/Wac.[37]

These PV costs compare to a capital cost range for solar thermal, assumed to be dry-cooled, of $5.35 to $5.55/Wac. RETI indicates the capacity factor for thin-film PV is essentially the same as for dry-cooled solar thermal (assuming the same location). The capacity factor for single-axis tracking polysilicon PV is significantly better than that of dry-cooled solar thermal (assuming the same location). Operations and maintenance cost for either fixed thin-film PV or single-axis

[35] Navigant, *PV Grid Connected Market Potential under a Cost Breakthrough Scenario*, prepared for The Energy Foundation, September 2004, p. 83. California commercial rooftop PV potential estimated at approximately 37,000 MWp.
[36] RETI, *Phase 2B Final Report*, May 2010, p. 4-6.
[37] Ibid, Tables 4-5, 4-7, 4-8, pp. 4-6 and 4-7.

tracking polysilicon PV is lower than for dry-cooled solar thermal. This RETI data is summarized in Table 2 below.

Table 2. RETI capital cost, capacity factor, and O&M cost – dry-cooled solar thermal, fixed thin-film PV, and single-axis tracking polysilicon PV

Solar Technology	Capital Cost ($/kWac)	Capacity Factor (%)	O&M Cost ($/MWh)
Dry-cooled solar thermal	5,350 – 5,550	20 – 28	30
Fixed thin-film PV	3,600 – 4,000	20 - 27	20 - 27
Single-axis tracking polysilicon PV	4,000 – 5,000	23 - 31	17 - 25

The RSA comment on the capacity factors of solar thermal and rooftop PV is out-of-date (p. B.2-63): "The Renewable Energy Transmission Initiative (RETI) assumed a capacity factor of approximately 30 percent for solar thermal technologies and tracking solar PV and approximately 20 percent capacity factor for rooftop solar PV which is assumed to be non-tracking, for viable solar generation project locations (B&V 2008; CEC 2009)." As shown in Table 2, the RETI capacity factors of solar thermal and fixed (rooftop) solar PV are essentially the same assuming the same location.

The effect of the values in Table 2 on the levelized cost-of-energy (COE) for dry-cooled solar thermal, fixed thin-film PV, and single-axis tracking polysilicon PV is shown in Table 3.[38] The average levelized COE for either fixed thin-film PV or single-axis tracking polysilicon PV is significantly lower than the levelized COE of dry-cooled solar thermal plants.

Table 3. RETI cost-of energy (COE) comparison - dry-cooled solar thermal, fixed thin-film PV, and single-axis tracking polysilicon PV

Solar Technology	Levelized COE ($/MWh)
Dry-cooled solar thermal	$195 – 226 (mean: $210)
Fixed thin-film PV	$135 – 214 (mean: $175)
Single-axis tracking polysilicon PV	$138 – 206 (mean: $172)

The CPUC determined that there would be little difference in the cost of meeting state renewable energy targets by relying predominantly on distributed PV, when current state-of-the-art pricing is assumed, instead of building 10,000 MW of remote solar capacity under the 33 percent RPS reference case.[39] This conclusion was reached despite a number of controversial cost assumptions by the CPUC that favored the 33 percent RPS reference case.[40] An additional controversial assumption is the low assumed cost of new transmission to realize the 33 percent reference case. The CPUC assumed the total cost of new transmission would be $12 billion. The

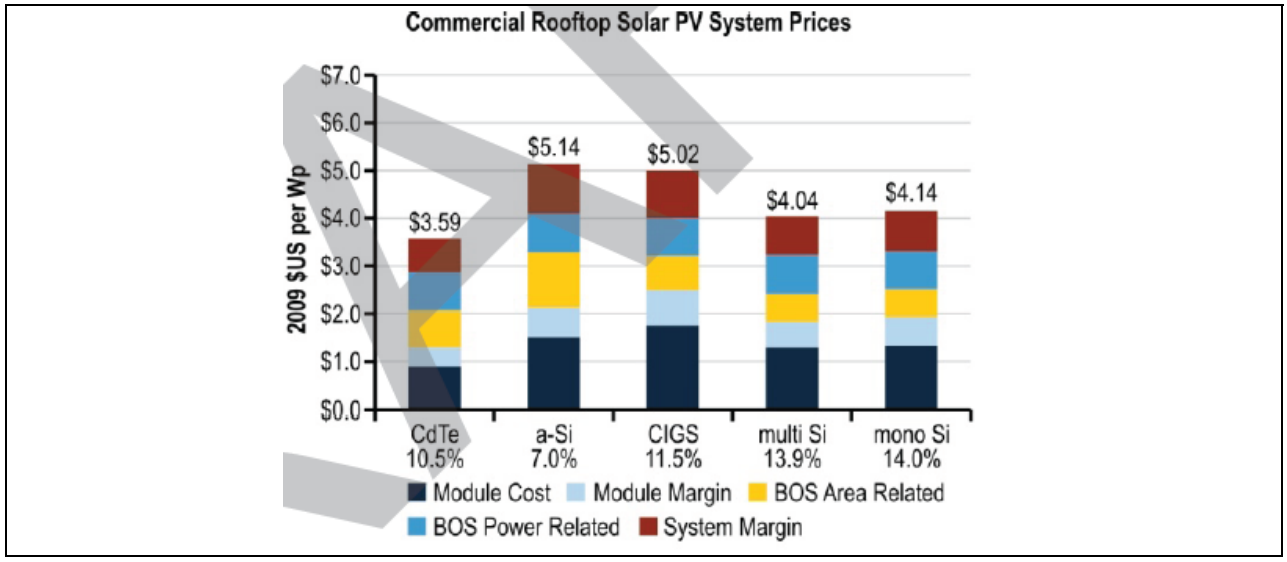
[38] Ibid, Figure 4-1, p. 4-8.
[39] CPUC, *33% Renewables Portfolio Standard Implementation Analysis Preliminary Results*, June 2009, p. 31.
[40] RightCycle Inc. comment letter, working group member response to June 2009 *33% Renewables Portfolio Standard Implementation Analysis Preliminary Results*, in response to CPUC request for comments, August 28, 2009.

current estimate is over $27 billion.[41] When current projections regarding the cost of new transmission and associated upgrades are used, the high distributed generation alternative is more cost-effective than the 33 percent reference case.

The RETI capital cost values for PV assume 20 MW systems located at distribution substations. However, even the cost of individual commercial rooftop PV installations is now lower than the RETI cost of $5.35 to $5.55/Wac for dry-cooled solar thermal plants.

The May 2010 DOE Solar Vision Study (draft) projection of current commercial rooftop PV capital cost is provided in Figure 3.[42] These capital cost values are provided in Wdc. As shown in Figure 2, the current capital cost of commercial rooftop polysilicon PV (multi Si and mono Si) is approximately $4/Wdc. RETI identifies the range of dc-to-ac conversion factors of 0.77 to 0.85.[43] Using an average dc-to-ac conversion factor of 0.80, the capital cost of commercial rooftop polysilicon PV is approximately $4/Wdc ÷ 0.80 = $5/Wac. This is incrementally less than the $5.35 to $5.55/Wac capital cost of dry-cooled solar thermal, and the commercial rooftop PV array could be as little as 1/1,000th the size of the solar thermal plant. The most common form of thin-film PV, CdTe (cadmium-telluride), is lower in cost than polysilicon PV at approximately $3.60/Wdc. This converts to $3.60/Wdc ÷ 0.80 = $4.50/Wac.

Figure 3. Cost of commercial rooftop PV identified by DOE



a-Si: amorphous silicon thin-film PV; CIGS: copper-indium-gallium-selenide thin-film PV.

[41] J. Firooz, P.E., CAISO: *How Its Transmission Planning Process has Lost Sight of the Public's Interest*, April 2010, Table 2, p. 10. Total new transmission and upgrades necessary to realize 33 percent RPS reference case as of September 2009 - $27.544 billion.
[42] DOE, *DOE Solar Vision Study – DRAFT*, May 28, 2010, Chapter 4, Figure 4-4, p. 7.
[43] RETI, *Phase 1A Final Report*, August 2008, Appendix B, p. 5-5.

H. Market Price Referent with Adjustment for On-Peak Power Output Benefit of Distributed PV would be Sufficient Price to Assure Rapid Construction of 500 MW Distributed PV Alternative to PSPP

The MPR that renewable energy projects are currently compared to, the cost of power generation from a hypothetical new natural gas-fired baseload power plant, is $0.12126/kWh.[44] Solar PV produces a substantial amount of output during on-peak summer demand periods. The electric power tariff during summer on-peak periods is much higher than the average tariff over the course of a year. For example, SCE's tariff pays 3.13 times the base MPR for deliveries during the summer on-peak period.[45] SCE has determined that the adjusted MPR for a distributed PV system is 1.39 times the MPR for a baseload plant.[46] Multiplying the $0.12126/kWh MPR by 1.39 gives an adjusted MPR of $0.169/kWh. This price alone, based on my experience with the current pricing of distributed PV PPAs, may be a sufficient price signal for private developers to rapidly develop large-scale distributed PV in SCE and PG&E service territories.

However, the transmission & distribution benefits of distributed PV are real and have been quantified.[47] The estimated value range of the transmission and distribution benefits of distributed PV include $0.058/kWh in SDG&E territory and $0.023 to $0.037/kWh in SCE territory. The transmission & distribution benefits of distributed PV in PG&E territory vary widely. Some examples in PG&E territory include Fresno at $0.026/kWh and Stockton at $0.039/kWh. These estimates were developed using the E3 model for calculating transmission & distribution benefits.[48]

An MPR-adjusted price of $0.169/kWh, plus an average transmission & distribution benefit of approximately $0.030/kWh, is equivalent to an overall value to the IOU of approximately $0.20/kWh. Any price paid for distributed PV by an IOU below this price threshold should result in a net benefit to all of the IOU's ratepayers. A distributed PV price in the range $0.20/kWh would be more than sufficient to create a dynamic market for third party development of large-scale distributed PV in California urban areas.

I. Rooftop Commercial PV is More Space Efficient than PSPP and has None of the Environmental Impacts of PSPP

The RSA states, without citation: "However, based on SCE's use of 600,000-square-feet for 2 MW(ac) of energy, 150 million square feet (approximately 3,500 acres) would be required for 500 MW" (p. B2-63). This equals 7 acres per MWac of capacity. SCE states in its March 2008 solar PV program testimony that 125,000 square feet of polysilicon panels are required to generate 1 MWdc.[49] This converts to about 150,000 square feet per MWac, or approximately 3.5

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[44] CPUC Resolution E-4214, *2008 Market Price Referent values for use in the 2008 Renewable Portfolio Standard solicitations*, December 18, 2008. MPR, 2012 operational date, 20-yr PPA: $0.12126/kWh.
[45] SCE Application A.08-03-015, *Solar Photovoltaic (PV) Program Supplemental Rebuttal Testimony*, October 14, 2008, p. 3, footnote 2. "ToD (time of day) adjustment estimate calculated as weighted average of (512 summer – on hours at 3.13, 768 summer – mid at 1.35, and 2,189 winter – mid hours at 1.00) = 1.39."
[46] Ibid.
[47] CPUC Rulemaking R.06-02-012, Develop Additional Methods to Implement California RPS Program, *Pre-Workshop Comments of GreenVolts, Cleantech America, and Community Environmental Council on the 2008 Market Price Referent*, March 6, 2008, p. 15.
[48] Ibid, p. 14.
[49] SCE Application A.08-03-015, *Solar Photovoltaic (PV) Program Testimony*, March 27, 2008, p. 32.

acres per MWac.[50] This is one-half the square-footage per MWac that the RSA erroneously attributes to SCE rooftop installations. SCE's actual testimony on rooftop PV space requirements contradicts the RSA citation attributed to SCE on the same topic. SCE has signed contracts with SunPower and Trina Solar, both suppliers of polysilicon PV panels, to provide a combined total of 245 MW of the 500 MW of PV capacity that will be owned by SCE.[51,52]

The RSA estimate of the space requirement for ground-mounted polysilicon PV arrays validates the 3.5 acre space requirement identified by SCE for rooftop polysilicon PV. In the section of the RSA that discusses utility-scale solar PV, the RSA states (p. B.2-60): "The land requirement varies from approximately 3 acres per MW of capacity for crystalline silicon . . ."

Rooftop PV is also approximately twice as space efficient as the PSPP project. The RSA states that 2,970 acres will be developed to produce 500 MWac (p. B.1-1). This is approximately 6 acres per MWac, and nearly double the 3.5 acre per MWac space requirement of the rooftop polysilicon PV alternative.

The predominant advantage of rooftop (or parking lot) PV is that it represents a compatible dual use of existing developed structures with no environmental impacts. As the RSA correctly notes, "The PV panels could be installed on residential, commercial, or industrial building rooftops or in other disturbed areas such as parking lots or disturbed areas adjacent to existing structures such as substations." (p. B.2-62).

J. RSA Concerns about Sufficient PV Panel Manufacturing Capacity Are Baseless

The concerns expressed in the RSA regarding the availability of distributed solar PV are without foundation. The RSA states (p. B.2-66): "While it will very likely be possible to achieve 500 MW of distributed solar energy over the coming years, the very limited numbers of existing facilities make it difficult to conclude with confidence that it will happen within the timeframe required for the PSPP. As a result, this technology is eliminated from detailed analysis in this SA/DEIS." Over 21,000 MW of PV systems, most of them distributed PV systems, were operational worldwide by the end of 2009.[53] More than 7,000 MW of PV was installed worldwide in 2009 alone.[54] In contrast, only 127 MW of solar thermal plants were constructed in 2009.[55]

Thin-film PV manufacturing capacity is projected to reach 7,400 MW per year in 2010.[56] First Solar alone manufactured and shipped more than 1,000 MW of thin-film panels in 2009.[57]

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[50] There are 43,560 square feet per acre. Therefore, 150,000 square feet per MWac ÷ 43,560 square feet per acre = 3.44 acre/MWac.
[51] SNL Financial, *SoCalEd orders 200 MW of solar panels, plans solicitation for 250 MW more*, March 10, 2010.
[52] SNL Financial, *SoCalEd taps Trina Solar to supply 45 MW of PV modules*, June 9, 2010.
[53] Worldwatch Institute, *Record Growth in Photovoltaic Capacity and Momentum Builds for Concentrating Solar Power*, June 3, 2010.
[54] Ibid.
[55] Ibid.
[56] Schreiber, D. - EuPD Research, *PV Thin-film Markets, Manufacturers, Margins*, presentation at 1st Thin-Film Summit, San Francisco, December 1-2, 2008.
[57] First Solar press release, *First Solar Becomes First PV Company to Produce 1GW in a Single Year*, December 15, 2009.

Worldwide conventional polysilicon PV production capacity reached 13,300 MW a year in 2008.[58] It is projected to reach 20,000 MW a year in 2010. The 2010 projections were made just as the economic slump began in late 2008. It is likely there will be some scale-back on the 2010 capacity additions due to the state of the world economy. Nonetheless, there is a tremendous amount of available worldwide PV manufacturing capacity.

PV panel manufacturing capacity has greatly expanded worldwide in the last 2 to 3 years. The current estimated oversupply of PV panel manufacturing capacity for 2010 is 8,000 MW.[59] As a result of this oversupply, the cost of conventional polysilicon PV panels has dropped precipitously and is approaching the cost of thin-film PV panels (see Figure 3).

The RSA states that California added 158 MW of distributed PV in 2008 (p. B.2-62). California is a relatively minor player on the world PV stage. Spain added approximately 2,500 MW of primarily distributed ground-mounted PV resources in 2008.[60] Spain has a smaller economy than California. Germany, approximately the same size as California and with considerably lower solar intensity, added approximately 1,500 MW of distributed PV resources in 2008,3,800 MW in 2009, and added 4,900 MW in the first eight months of 2010.[61,62,63] Germany had an installed PV capacity of approximately 13,000 MW as of September 1, 2010.[64]

The RSA expresses concerns regarding the feasibility of California doubling its 158 MW per year (2008) distributed PV installation rate as a substitute for PSPP, stating (p. B.2-64): "This would require an even more aggressive deployment of PV at more than double the historic rate of solar PV implementation than the California Solar Initiative program currently employs." This doubling of distributed PV deployment is equivalent to going from 1/40th to 1/20th the current German distributed PV installation rate. The feasibility concern expressed in the RSA is unfounded in light of German success with a high rate of distributed PV deployment.

The high distributed PV alternative studied by the CPUC anticipates the installation of 15,000 MW of distributed PV by 2020.[65] RETI has gradually dropped the amount of new renewable energy resources needed to reach 33 percent by 2020, the "net short," from 74,650 gigawatt-hours (GWh) per year initially to a current "low load" net short of 36,926 MW.[66] The low load net short is one-half the net short used by the CPUC in June 2009 to estimate the cost of achieving 33 percent by 2020. 15,000 MW of distributed PV would provide about 30,000

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[58] Schreiber, D. - EuPD Research, *PV Thin-film Markets, Manufacturers, Margins*, presentation at 1st Thin-Film Summit, San Francisco, December 1-2, 2008.
[59] B. Murphy – Fulcrum Technologies, Inc., *The Power and Potential of CdTe (thin-film) PV*, presented at 2nd Thin-Film Summit, San Francisco, December 1-2, 2009.
[60] PV Tech, *Worldwide photovoltaics installations grew 110% in 2008, says Solarbuzz*, March 16, 2009.
[61] PV Tech, *German market booming: Inverter and module supplies running out at Phoenix Solar*, November 15, 2009.
[62] Worldwatch Institute, *Record Growth in Photovoltaic Capacity and Momentum Builds for Concentrating Solar Power*, June 3, 2010.
[63] Renewable Energy World, *Germany Adds Nearly 1% of Electricity Supply with Solar in Eight Months*, October 4, 2010.
[64] Chadbourne & Parke Project Finance Newswire, *Germany Cuts Solar Subsidy*, April 2010. Adding the 4,900 MW constructed in Germany in the first 8 months of 2010 to the 9,000 MW installed through the end of 2009 gives a German total of approximately 13,000 MW.
[65] CPUC, *33% Renewables Portfolio Standard Implementation Analysis Preliminary Results*, June 2009.
[66] RETI discussion draft, *RETI Net Short Update - Evaluating the Need for Expanded Electric Transmission Capacity for Renewable Energy*, February 22, 2010. Low load scenario, net short = 36,926 MW.

GWh/yr.[67] 15,000 MW of distributed PV would provide over 80 percent of the low load net short of 36,926 MW.

California could easily install 15,000 MW of distributed PV by 2020 if it approached the annual distributed PV installation rates that have already been achieved in practice in Spain and Germany. Existing worldwide PV manufacturing capacity, either thin-film alone or thin-film and conventional polysilicon, could readily supply a PV demand of 1,500 to 2,500 MW a year in California.

K. Slight Reduction in Output from Distributed PV in Los Angeles, Central Valley, or Bay Area Is Offset by Transmission Losses from PSPP to These Load Centers

The RSA implies that the superior solar intensity at the PSPP location in the Mojave Desert is a substantive reason for eliminating distributed PV from consideration, stating (p. B.2-64):

"The solar Technology (distributed PV) would not necessarily meet the objective to locate the facility in areas of high solarity, because the distributed technology could be located throughout the State."

The solar insolation at the PSPP site is about 10 to 15 percent better than the composite solar insolation for Los Angeles, the Central Valley, and Oakland.[68,69] However, the CEC estimates average transmission losses in California at 7.5 percent and peak transmission losses at 14 percent.[70] The incrementally better solar insolation at the PSPP site is almost completely negated by the losses incurred by transmitting PSPP solar power to California urban areas. In contrast, distributed PV has minimal losses between generation and user.

L. CEC Has Already Determined Distributed PV Can Compete Cost-Effectively with Other Forms of Generation

The CEC denied an application for a 100-megawatt natural-gas-fired gas turbine power plant, the Chula Vista Energy Upgrade Project (CVEUP), in June 2009 in part because rooftop solar PV could potentially achieve the same objectives for comparable cost.[71]

This June 2009 CEC decision implies that any future applications for gas-fired generation in California, or any other type of generation including remote central station renewable energy generation like PSPP that require public land and new transmission to reach demand centers,

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[67] The CPUC reference case assumes 3,235 MW of solar PV will generate 6,913 GWh per year under ideal Southern California desert solar insolation conditions. This is a production ratio of 2,137 GWh per MWac. However, solar insolation in the Central Valley and California urban areas will on average be approximately 10 less than ideal desert sites. For this reason a production ratio of 2,000 GWh per year per MWac is assumed for the Central Valley and urban areas.

[68] U.S. DOE, *Stand-Alone Flat-plate Photovoltaic Systems: System Sizing and Life-Cycle Costing Methodology for Federal Agencies*, 1984, Appendix, p. A-27.

[69] NREL, *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, California cities data: http://rredc.nrel.gov/solar/pubs/redbook/PDFs/CA.PDF

[70] E-mail communication between Don Kondoleon, manager - CEC Transmission Evaluation Program, and Bill Powers of Powers Engineering, January 30, 2008.

[71] CEC, Chula Vista Energy Upgrade Project - Application for Certification (07-AFC-4) San Diego County, *Final Commission Decision*, June 2009.

should be measured against using urban PV to meet the power need. The CEC's final decision in the CVEUP case stated:[72]

> "Photovoltaic arrays mounted on existing flat warehouse roofs or on top of vehicle shelters in parking lots do not consume any acreage. The warehouses and parking lots continue to perform those functions with the PV in place. (Ex. 616, p. 11.)….Mr. Powers (expert for intervenor) provided detailed analysis of the costs of such PV, concluding that there was little or no difference between the cost of energy provided by a project such as the CVEUP (gas turbine peaking plant) compared with the cost of energy provided by PV. (Ex. 616, pp. 13 – 14.)….PV does provide power at a time when demand is likely to be high—on hot, sunny days. Mr. Powers acknowledged on cross-examination that the solar peak does not match the demand peak, but testified that storage technologies exist which could be used to manage this. The essential points in Mr. Powers' testimony about the costs and practicality of PV were uncontroverted."

The CEC concluded in the CVEUP final decision that PV arrays on rooftops and over parking lots may be a viable alternative to the gas turbine project proposed in that case, and that if the gas turbine project proponent opted to file a new application a much more detailed analysis of the PV alternative would be required.

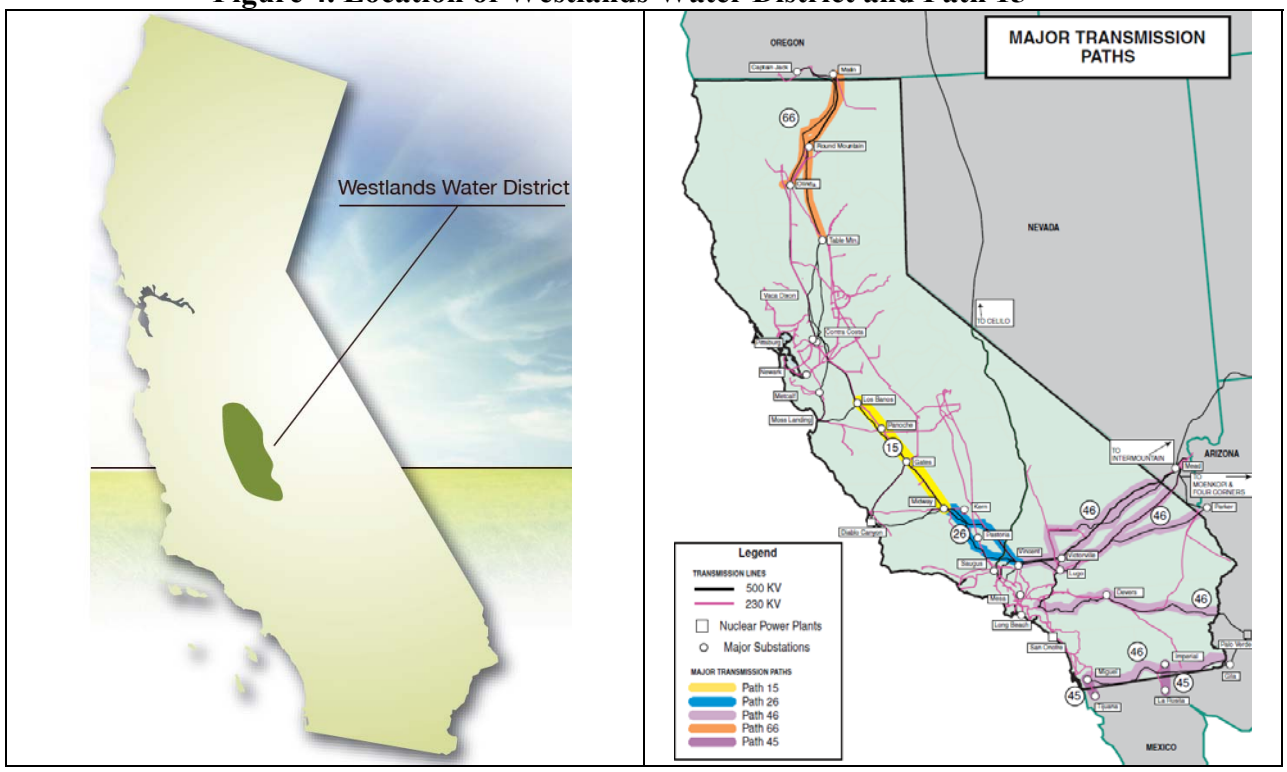
IV. Locating PSPP in the Proposed Westlands Water District CREZ would Avoid Environmental Impacts at the PSPP Site

The Westlands Water District ("Westlands"), on the west side of the Central Valley, is undergoing study by RETI as a Competitive Renewable Energy Zone (CREZ) capable of providing 5,000 MW of utility-scale solar development. Westlands covers over 600,000 acres of farmland in western Fresno and Kings Counties. The proposed "Central California Renewable Master Plan" will utilize permanently retired farmlands in Westlands for solar development. An overview of this master plan is attached. As stated in the master plan overview, "Due to salinity contamination issues, a portion of this disturbed land has been set aside for retirement and will be taken out of production under an agreement between Westlands and the U.S. Department of Interior." Approximately 30,000 acres of disturbed Westlands land, equivalent to 5,000 MW of solar capacity, will be allocated for renewable energy development under the plan.

Transmission Pathway 15 passes through Westlands. Path 15 can transmit 5,400 MW from south-to-north.[73] The transmission capacity from north-to-south is 3,400 MW. The location of Westlands relative to Path 15 is shown in Figure 4.

[72] Ibid, pp. 29-30.
[73] Transmission & Distribution World, *California bulks up to provide more transmission capacity*, June 1, 2004.

Figure 4. Location of Westlands Water District and Path 15[74,75]



5,000 MW of solar power can be developed in Westlands with potentially no expansion of the existing Path 15 high voltage transmission capacity that serves Westlands now.

5,000 MW is half of the total remote in-state utility-scale solar contemplated in the June 2009 CPUC 33 percent reference case.[76] The remote in-state solar component of the reference case consists of 3,235 MW central station PV and 6,764 MW central station solar thermal. The anticipated energy output of 5,000 MW of fixed PV in Westlands would be about 10,000 GWh/yr.[77] This is approximately 30 percent of the RETI low load net short of 36,926 MW.

Site control would not be an issue in the proposed Westlands CREZ. Westlands is actively marketing the 30,000-acre area for development of central station solar power plants. Development of solar projects on the Westlands property is intended (by Westlands) to serve as a source of income on land that has been permanently retired from agricultural production.

Prioritizing distributed PV projects, combined with the location of central station solar projects in Westlands, would allow California to achieve its 33 percent by 2020 renewable energy target with almost no environmental impacts related to the solar energy component of the renewable energy portfolio.

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[74] Anthem Group press release, *Central California Renewable Master Plan*, March 2010.
[75] CEC, *Strategic Transmission Investment Plan*, November 2005, p. 11.
[76] CPUC, *33% RPS Implementation Analysis Preliminary Results*, June 2009, Appendix C, p. 87.
[77] The CPUC reference case assumes 3,235 MW of solar PV will generate 6,913 GWh per year under ideal Southern California desert solar insolation conditions. This is a production ratio of 2,137 GWh per MWac. However, solar insolation in the Central Valley and California urban areas will on average be approximately 10 less than ideal desert sites. For this reason a production ratio of 2,000 GWh per year per MWac is assumed for the Central Valley and urban areas.

V. Conclusions

The RSA analysis of the distributed PV alternative to PSPP uses flawed logic and outdated data to improperly eliminate distributed PV as an alternative. In fact, distributed PV is a fully viable and cost-effective alternative that eliminates the environmental impacts that would be caused by the PSPP project. The RSA should have concluded that distributed PV is a superior alternative to the PSPP project.

Beyond the issue of distributed PV being a superior alternative to PSPP on cost and environmental grounds, there are lower-impact sites in California for central station solar projects like PSPP. For example, the Westlands Water District is a low impact "shovel ready" alternative to the PSPP site for central station solar projects. The Westlands CREZ requires no new high voltage transmission to move up to 5,000 MW of solar power to California load centers. This means solar projects located in Westlands will not face project delays due to lack of high voltage transmission capacity. The steadily declining renewable energy net short to achieve the 33 percent by 2020 target, now as low as 36,926 MW, means fewer renewable projects overall are necessary to meet the 33 percent target. The CEC should not approve solar projects with unmitigatable impacts like PSPP while 5,000 MW of otherwise unusable disturbed land with no environmental issues and 5,000 MW of high voltage transmission capacity sit idle.

Declaration of Bill Powers, P.E.,

Re: Testimony on Alternatives to the Application for Certification for the Palen Solar Power Project

Docket No. 09-AFC-7

I, Bill Powers, declare as follows:

1) I am a self-employed consulting engineer.

2) My relevant professional qualifications and experience are set forth in the attached resume and the attached testimony and are incorporated herein by reference.

3) I prepared the testimony attached hereto and incorporated herein by reference, relating to the distributed PV alternative to the project.

4) I prepared the testimony attached hereto and incorporated herein by reference relating to the proposed Palen Solar Power Project.

5) It is my professional opinion that the attached testimony is true and accurate with respect to the issues that it addresses.

6) I am personally familiar with the facts and conclusions described within the attached testimony and if called as a witness, I could testify competently thereto.

I declare under penalty of perjury that the foregoing is true and correct to the best of my knowledge and belief.

Dated: Oct. 4, 2010 Signed: Bill Powers, P.E.

At: San Diego, CA

BILL POWERS, P.E.

PROFESSIONAL HISTORY

Powers Engineering, San Diego, CA 1994-
ENSR Consulting and Engineering, Camarillo, CA 1989-93
Naval Energy and Environmental Support Activity, Port Hueneme, CA 1982-87
U.S. Environmental Protection Agency, Research Triangle Park, NC 1980-81

EDUCATION

Master of Public Health – Environmental Sciences, University of North Carolina
Bachelor of Science – Mechanical Engineering, Duke University

PROFESSIONAL AFFILIATIONS

Registered Professional Mechanical Engineer, California (Certificate M24518)
American Society of Mechanical Engineers
Air & Waste Management Association

TECHNICAL SPECIALTIES

Twenty-five years of experience in:

- San Diego and Baja California regional energy planning
- Power plant technology, emissions, and cooling system assessments
- Combustion and emissions control equipment permitting, testing, monitoring
- Oil and gas technology assessment and emissions evaluation
- Latin America environmental project experience

SAN DIEGO AND BAJA CALIFORNIA REGIONAL ENERGY PLANNING

San Diego Smart Energy 2020 Plan. Author of October 2007 "San Diego Smart Energy 2020," an energy plan that focuses on meeting the San Diego region's electric energy needs through accelerated integration of renewable and non-renewable distributed generation, in the form of combined heat and power (CHP) systems and solar photovoltaic (PV) systems. PV would meet approximately 28 percent of the San Diego region's electric energy demand in 2020. CHP systems would provide approximately 47 percent. Annual energy demand would drop 20 percent in 2020 relative to 2003 through use all cost-effective energy efficiency measures. This target is based on City of San Diego experience. San Diego has consistently achieved energy efficiency reductions of 20 percent on dozens of projects. Existing utility-scale gas-fired generation would continue to be utilized to provide power at night, during cloudy whether, and for grid reliability support.

Photovoltaic technology selection and siting for SDG&E Solar San Diego project. Served as PV technology expert in California Public Utilities Commission proceeding to define PV technology and sites to be used in San Diego Gas & Electric (SDG&E) $250 million "Solar San Diego" project. Recommendations included: 1) prioritize use of roof-mounted thin-film PV arrays similar to the SCE urban PV program to maximize the installed PV capacity, 2) avoid tracking ground-mounted PV arrays due to high cost and relative lack of available land in the urban/suburban core, 3) and incorporate limited storage in fixed rooftop PV arrays to maximizing output during peak demand periods. Suitable land next to SDG&E substations capable of supporting 5 to 40 MW of PV (each) was also identified by Powers Engineering as a component of this project.

Photovoltaic arrays as alternative to natural gas-fired peaking gas turbines, Chula Vista. Served as PV technology expert in California Energy Commission (CEC) proceeding regarding the application of MMC Energy to build a 100 MW peaking gas turbine power plant in Chula Vista. Presented testimony that 100 MW of PV arrays in the Chula Vista area could provide the same level of electrical reliability on hot summer days as

an equivalent amount of peaking gas turbine capacity at approximately the same cost of energy. The preliminary decision issued by the presiding CEC commissioner in the case recommended denial of the application in part due to failure of the applicant or CEC staff to thoroughly evaluate the PV alternative to the proposed turbines. No final decision has yet been issued in the proceeding (as of May 2009).

San Diego Area Governments (SANDAG) Energy Working Group. Public interest representative on the SANDAG Energy Working Group (EWG). The EWG advises the Regional Planning Committee on issues related to the coordination and implementation of the Regional Energy Strategy 2030 adopted by the SANDAG Board of Directors in July 2003. The EWG consists of elected officials from the City of San Diego, County of San Diego and the four subareas of the region. In addition to elected officials, the EWG includes stakeholders representing business, energy, environment, economy, education, and consumer interests.

Development of San Diego Regional Energy Strategy 2030. Participant in the 18-month process in the 2002-2003 timeframe that led to the development of the San Diego Regional Energy Strategy 2030. This document was adopted by the SANDAG Board of Directors in July 2003 and defines strategic energy objectives for the San Diego region, including: 1) in-region power generation increase from 65% of peak demand in 2010 to 75% of peak demand in 2020, 2) 40% renewable power by 2030 with at least half of this power generated in-county, 3) reinforcement of transmission capacity as needed to achieve these objectives. The SANDAG Board of Directors voted unanimously on Nov. 17, 2006 to take no position on the Sunrise Powerlink proposal primarily because it conflicts the Regional Energy Strategy 2030 objective of increased in-region power generation. The Regional Energy Strategy 2030 is online at: http://www.energycenter.org/uploads/Regional_Energy_Strategy_Final_07_16_03.pdf

Imperial Valley Study Group. Participant in the Imperial Valley Study Group (IVSG), and effort funded by the CEC to examine transmission options for maximizing the development of geothermal resources in Imperial County. Advised the IVSG that no alternatives other than the Sunrise Powerlink or a similar variant were be considered to move Imperial Valley geothermal generation to San Diego. Initiated a dialogue on IVSG's failure to consider alternatives that was incorporated into the IVSG April 12, 2005 meeting minutes (see: http://www.energy.ca.gov/ivsg/documents/2005-04-12_meeting/2005-04-12_AMNDED_IVSG_MINUTES.PDF). Also co-authored with the Utility Consumers' Action Network an October 14, 2005 alternative letter report to the September 30, 2005 IVSG final report that documents numerous feasible transmission alternatives to the Sunrise Powerlink that were not considered by IVSG. The October 14, 2005 IVSG alternative letter report also served as a comment letter on the CEC's 2005 Integrated Energy Policy Report webpage is available at: http://www.energy.ca.gov/2005_energypolicy/documents/2005-10-11_DER_comments/10-14 05_Utility_Consumers_Action_Network_BPPWG.pdf

COMBUSTION AND EMISSIONS CONTROL EQUIPMENT PERMITTING, TESTING, MONITORING

EPRI Gas Turbine Power Plant Permitting Documents – Co-Author. Co-authored two Electric Power Research Institute (EPRI) gas turbine power plant siting documents. Responsibilities included chapter on state-of-the-art air emission control systems for simple-cycle and combined-cycle gas turbines, and authorship of sections on dry cooling and zero liquid discharge systems.

Air Permits for 50 MW Peaker Gas Turbines – Six Sites Throughout California. Responsible for preparing all aspects of air permit applications for five 50 MW FT-8 simple-cycle turbine installations at sites around California in response to emergency request by California state government for additional peaking power. Units were designed to meet 2.0 ppm NO_x using standard temperature SCR and innovative dilution air system to maintain exhaust gas temperature within acceptable SCR range. Oxidation catalyst is also used to maintain CO below 6.0 ppm.

Kauai 27 MW Cogeneration Plant – Air Emission Control System Analysis. Project manager to evaluate technical feasibility of SCR for 27 MW naphtha-fired turbine with once-through heat recovery steam generator. Permit action was stalled due to questions of SCR feasibility. Extensive analysis of the performance of existing oil-fired turbines equipped with SCR, and bench-scale tests of SCR applied to naphtha-fired turbines, indicated

that SCR would perform adequately. Urea was selected as the SCR reagent given the wide availability of urea on the island. Unit is first known application of urea-injected SCR on a naphtha-fired turbine.

Microturbines – Ronald Reagan Library, Ventura County, California. Project manager and lead engineer or preparation of air permit applications for microturbines and standby boilers. The microturbines drive the heating and cooling system for the library. The microturbines are certified by the manufacturer to meet the 9 ppm NO_x emission limit for this equipment. Low-NO_x burners are BACT for the standby boilers.

Hospital Cogeneration Microturbines – South Coast Air Quality Management District. Project manager and lead engineer for preparation of air permit application for three microturbines at hospital cogeneration plant installation. The draft Authority To Construct (ATC) for this project was obtained two weeks after submittal of the ATC application. 30-day public notification was required due to the proximity of the facility to nearby schools. The final ATC was issued two months after the application was submitted, including the 30-day public notification period.

Gas Turbine Cogeneration – South Coast Air Quality Management District. Project manager and lead engineer for preparation of air permit application for two 5.5 MW gas turbines in cogeneration configuration for county government center. The turbines will be equipped with selective catalytic reduction (SCR) and oxidation catalyst to comply with SCAQMD BACT requirements. Aqueous urea will be used as the SCR reagent to avoid trigger hazardous material storage requirements. A separate permit will be obtained for the NO_x and CO continuous emissions monitoring systems. The ATCs is pending.

Industrial Boilers – NO_x BACT Evaluation for San Diego County Boilers. Project manager and lead engineer for preparation of Best Available Control Technology (BACT) evaluation for three industrial boilers to be located in San Diego County. The BACT included the review of low NO_x burners, FGR, SCR, and low temperature oxidation (LTO). State-of-the-art ultra low NO_x burners with a 9 ppm emissions guarantee were selected as NO_x BACT for these units.

Peaker Gas Turbines – Evaluation of NO_x Control Options for Installations in San Diego County. Lead engineer for evaluation of NO_x control options available for 1970s vintage simple-cycle gas turbines proposed for peaker sites in San Diego County. Dry low-NO_x (DLN) combustors, catalytic combustors, high-temperature SCR, and NO_x absorption/conversion ($SCONO_x$) were evaluated for each candidate turbine make/model. High-temperature SCR was selected as the NOx control option to meet a 5 ppm NO_x emission requirement.

Hospital Cogeneration Plant Gas Turbines – San Joaquin Valley Unified Air Pollution Control District. Project manager and lead engineer for preparation of air permit application and BACT evaluation for hospital cogeneration plant installation. The BACT included the review of DLN combustors, catalytic combustors, high-temperature SCR and $SCONO_x$. DLN combustion followed by high temperature SCR was selected as the NO_x control system for this installation. The high temperature SCR is located upstream of the heat recovery steam generator (HRSG) to allow the diversion of exhaust gas around the HRSG without compromising the effectiveness of the NO_x control system.

Industrial Cogeneration Plant Gas Turbines – Upgrade of Turbine Power Output. Project manager and lead engineer for preparation of BACT evaluation for proposed gas turbine upgrade. The BACT included the review of DLN combustors, catalytic combustors, high-, standard-, and low-temperature SCR, and $SCONO_x$. Successfully negotiated air permit that allowed facility to initially install DLN combustors and operate under a NO_x plantwide "cap." Within two major turbine overhauls, or approximately eight years, the NO_x emissions per turbine must be at or below the equivalent of 5 ppm. The 5 ppm NO_x target will be achieved through technological in-combustor NO_x control such as catalytic combustion, or SCR or SCR equivalent end-of-pipe NO_x control technologies if catalytic combustion is not available.

Gas Turbines – Modification of RATA Procedures for Time-Share CEM. Project manager and lead engineer for the development of alternate CO continuous emission monitor (CEM) Relative Accuracy Test Audit (RATA) procedures for time-share CEM system serving three 7.9 MW turbines located in San Diego. Close interaction with San Diego APCD and EPA Region 9 engineers was required to receive approval for the alternate CO RATA standard. The time-share CEM passed the subsequent annual RATA without problems as a result of changes to some of the CEM hardware and the more flexible CO RATA standard.

Gas Turbines – Evaluation of NO_x Control Technology Performance. Lead engineer for performance review of dry low-NO_x combustors, catalytic combustors, high-, standard-, and low-temperature selective catalytic reduction (SCR), and NO_x absorption/conversion ($SCONO_x$). Major turbine manufacturers and major manufacturers of end-of-pipe NO_x control systems for gas turbines were contacted to determine current cost and performance of NO_x control systems. A comparison of 1993 to 1999 "$/kwh" and "$/ton" cost of these control systems was developed in the evaluation.

Gas Turbines – Evaluation of Proposed NO_x Control System to Achieve 3 ppm Limit. Lead engineer for evaluation for proposed combined cycle gas turbine NO_x and CO control systems. Project was in litigation over contract terms, and there was concern that the GE Frame 7FA turbine could not meet the 3 ppm NO_x permit limit using a conventional combustor with water injection followed by SCR. Operations personnel at GE Frame 7FA installatins around the country were interviewed, along with principal SCR vendors, to corroborate that the installation could continuously meet the 3 ppm NO_x limit.

Gas Turbines – Title V "Presumptively Approvable" Compliance Assurance Monitoring Protocol. Project manager and lead engineer for the development of a "presumptively approval" NO_x parametric emissions monitoring system (PEMS) protocol for industrial gas turbines. "Presumptively approvable" means that any gas turbine operator selecting this monitoring protocol can presume it is acceptable to the U.S. EPA. Close interaction with the gas turbine manufacturer's design engineering staff and the U.S. EPA Emissions Measurement Branch (Research Triangle Park, NC) was required to determine modifications necessary to the current PEMS to upgrade it to "presumptively approvable" status.

Environmental Due Diligence Review of Gas Turbine Sites – Mexico. Task leader to prepare regulatory compliance due diligence review of Mexican requirements for gas turbine power plants. Project involves eleven potential sites across Mexico, three of which are under construction. Scope involves identification of all environmental, energy sales, land use, and transportation corridor requirements for power projects in Mexico. Coordinator of Mexican environmental subcontractors gathering on-site information for each site, and translator of Spanish supporting documentation to English.

Development of Air Emission Standards for Gas Turbines - Peru. Served as principal technical consultant to the Peruvian Ministry of Energy in Mines (MEM) for the development of air emission standards for Peruvian gas turbine power plants. All major gas turbine power plants in Peru are currently using water injection to increase turbine power output. Recommended that 42 ppm on natural gas and 65 ppm on diesel (corrected to 15% O_2) be established as the NO_x limit for existing gas turbine power plants. These limits reflect NO_x levels readily achievable using water injection at high load. Also recommended that new gas turbine sources be subject to a BACT review requirement.

Gas Turbines – Title V Permit Templates. Lead engineer for the development of standardized permit templates for approximately 100 gas turbines operated by the oil and gas industry in the San Joaquin Valley. Emissions limits and monitoring requirements were defined for units ranging from GE Frame 7 to Solar Saturn turbines. Stand-alone templates were developed based on turbine size and NO_x control equipment. NO_x utilized in the target turbine population ranged from water injection alone to water injection combined with SCR.

Gas Turbines – Evaluation of NO_x, SO_2 and PM Emission Profiles. Performed a comparative evaluation of the NO_x, SO_2 and particulate (PM) emission profiles of principal utility-scale gas turbines for an independent power producer evaluating project opportunities in Latin America. All gas turbine models in the 40 MW to 240 MW range manufactured by General Electric, Westinghouse, Siemens and ABB were included in the evaluation.

Stationary Internal Combustion Engine (ICE) RACT/BARCT Evaluation. Lead engineer for evaluation of retrofit NO_x control options available for the oil and gas production industry gas-fired ICE population in the San Joaquin Valley affected by proposed Best Available Retrofit Control Technology (BARCT) emission limits. Evaluation centered on lean-burn compressor engines under 500 bhp, and rich-burn constant and cyclically loaded (rod pump) engines under 200 bhp. The results of the evaluation indicated that rich burn cyclically-loaded rod pump engines comprised 50 percent of the affected ICE population, though these ICEs accounted for only 5 percent of the uncontrolled gas-fired stationary ICE NO_x emissions. Recommended retrofit NO_x control strategies included: air/fuel ratio adjustment for rod pump ICEs, Non-selective catalytic reduction (NSCR) for rich-burn, constant load ICEs, and "low emission" combustion modifications for lean burn ICEs.

Development of Air Emission Standards for Stationary ICEs - Peru. Served as principal technical consultant to the Peruvian Ministry of Energy in Mines (MEM) for the development of air emission standards for Peruvian stationary ICE power plants. Draft 1997 World Bank NO_x and particulate emission limits for stationary ICE power plants served as the basis for proposed MEM emission limits. A detailed review of ICE emissions data provided in PAMAs submitted to the MEM was performed to determine the level of effort that would be required by Peruvian industry to meet the proposed NO_x and particulate emission limits. The draft 1997 WB emission limits were revised to reflect reasonably achievable NO_x and particulate emission limits for ICEs currently in operation in Peru.

Air Toxics Testing of Natural Gas-Fired ICEs. Project manager for test plan/test program to measure volatile and semi-volatile organic air toxics compounds from fourteen gas-fired ICEs used in a variety of oil and gas production applications. Test data was utilized by oil and gas production facility owners throughout California to develop accurate ICE air toxics emission inventories.

Ethanol Plant Dryer – Penn-Mar Ethanol, LLC. Lead engineer on BACT evaluation for ethanol dryer. Dryer nitrogen oxide (NO_x) emission limit of 30 ppm determined to be BACT following exhaustive review of existing and pending ethanol plant air permits and discussions with principal dryer vendors.

BARCT Low NO_x Burner Conversion – Industrial Boilers. Lead engineer for a BARCT evaluation of low NO_x burner options for natural gas-fired industrial boilers. Also evaluated methanol and propane as stand-by fuels to replace existing diesel stand-by fuel system and replacement of steam boilers with gas turbine co-generation system.

BACT Packed Tower Scrubber/Mist Eliminator Performance Evaluations. Project manager and lead engineer for Navy-wide plating shop air pollution control technology evaluation and emissions testing program. Mist eliminators and packed tower scrubbers controlling metal plating processes, which included hard chrome, nickel, copper, cadmium and precious metals plating, were extensively tested at three Navy plating shops. Chemical cleaning and stripping tanks, including hydrochloric acid, sulfuric acid, chromic acid and caustic, were also tested. The final product of this program was a military design specification for plating and chemical cleaning shop air pollution control systems. The hydrochloric acid mist sampling procedure developed during this program received a protected patent.

BACT Packed Tower Scrubber/UV Oxidation System Pilot Test Program. Technical advisor for pilot test program of packed tower scrubber/ultraviolet (UV) light VOC oxidation system controlling VOC emissions

from microchip manufacturing facility in Los Angeles. The testing was sponsored in part by the SCAQMD's Innovative Technology Demonstration Program, to demonstrate this innovative control technology as BACT for microchip manufacturing operations. The target compounds were acetone, methylethylketone (MEK) and 1,1,1-trichloroethane, and compound concentrations ranged from 10-100 ppmv. The single stage packed tower scrubber consistently achieved greater than 90% removal efficiency on the target compounds. The residence time required in the UV oxidation system for effective oxidation of the target compounds proved significantly longer than the residence time predicted by the manufacturer.

BACT Pilot Testing of Venturi Scrubber on Gas/Aerosol VOC Emission Source. Technical advisor for project to evaluate venturi scrubber as BACT for mixed phase aerosol/gaseous hydrocarbon emissions from deep fat fryer. Venturi scrubber demonstrated high removal efficiency on aerosol, low efficiency on VOC emissions. A number of VOC tests indicated negative removal efficiency. This anomaly was traced to a high hydrocarbon concentration in the scrubber water. The pilot unit had been shipped directly to the jobsite from another test location by the manufacturer without any cleaning or inspection of the pilot unit.

Pulp Mill Recovery Boiler BACT Evaluation. Lead engineer for BACT analysis for control of SO_2, NO_x, CO, TNMHC, TRS and particulate emissions from the proposed addition of a new recovery furnace at a kraft pulp mill in Washington. A "top down" approach was used to evaluate potential control technologies for each of the pollutants considered in the evaluation.

Air Pollution Control Equipment Design Specification Development. Lead engineer for the development of detailed Navy design specifications for wet scrubbers and mist eliminators. Design specifications were based on field performance evaluations conducted at the Long Beach Naval Shipyard, Norfolk Naval Shipyard, and Jacksonville Naval Air Station. This work was performed for the U.S. Navy to provide generic design specifications to assist naval facility engineering divisions with air pollution control equipment selection. Also served as project engineer for the development of Navy design specifications for ESPs and fabric filters.

POWER PLANT TECHNOLOGY, EMISSIONS, AND COOLING SYSTEM ASSESSMENTS

IGCC and Low Water Use Alternatives to Eight Pulverized Coal Fired 900 MW Boilers. Expert for cities of Houston and Dallas on integrated gasification combined cycle (IGCC) as a fully commercial coal-burning alternative to the pulverized coal (PC) technology proposed by TXU for eight 900 MW boilers in East Texas. Also analyzed East Texas as candidate location for CO_2 sequestration due to presence of mature oilfield CO_2 enhanced oil recovery opportunities and a deep saline aquifer underlying the entire region. Presented testimony on the major increase in regional consumptive water use that would be caused by the evaporative cooling towers proposed for use in the PC plants, and that consumptive water use could be lowered by using IGCC with evaporative cooling towers or by using air-cooled condensers with PC or IGCC technology. TXU ultimately dropped plans to build the eight PC plants as a condition of a corporate buy-out.

Assessment of CO_2 Capture and Sequestration for IGCC Plants. Author of assessment prepared for a public interest client of CO_2 capture and sequestration options for IGCC plants. The assessment focuses on: 1) CO_2 sequestration performance of operational large-scale CO_2 sequestration projects, specifically the Weyburn CO_2 enhanced oil recovery (EOR) project, and 2) CO_2 EOR as the vehicle to offset the cost of CO_2 capture and serve as the platform for an initial set of U.S. IGCC plants equipped for full CO_2 capture and storage.

Assessment of IGCC Alternative to Proposed 250 MW Circulating Fluidized Bed (CFB) Unit. Lead engineer to evaluate IGCC option to proposed 250 MW CFB firing Powder River Basin coal. Project site is in Montana, where CO_2 EOR opportunities exist in the eastern part of the state.

500 MW Coal-Fired Plant –Air Cooling and IGCC. Provided expert testimony on the performance of air-cooling and IGCC relative to the conventional closed-cycle wet cooled, supercritical pulverized coal boiler proposed by the applicant. Steam Pro™ coal-fired power plant design software was used to model the proposed plant and evaluate the impacts on performance of air cooling and plume-abated wet cooling. Results

indicated that a conservatively designed air-cooled condenser could maintain rated power output at the design ambient temperature of 90 ^{o}F. The IGCC comparative analysis indicated that unit reliability comparable to a conventional pulverized coal unit could be achieved by including a spare gasifier in the IGCC design, and that the slightly higher capital cost of IGCC was offset by greater thermal efficiency and reduced water demand and air emissions.

Retrofit of SCR to Existing Natural Gas-Fired Units. Lead expert in successful representation of interests of the city of Carlsbad, California to prevent weakening of an existing countywide utility boiler NO_x rule. Weakening of NO_x rule would have allowed a 1,000 MW merchant utility boiler plant located in the city to operate without installing selective catalytic reduction (SCR) NO_x control systems. Ultimately the plant owner was compelled to comply with the existing NO_x rule and install SCR on all five boilers at the plant. This project required numerous appearances before the county air pollution control hearing board to successfully defend the existing utility boiler NO_x rule.

Proposed 1.500 MW Pulverized Coal Power Plant. Provided testimony challenge to air permit issued for Peabody Coal Company's proposed 1,500 MW pulverized-coal fired power plant in Kentucky. Presented case that IGCC is a superior method for producing power from coal, from both environmental and energy efficiency perspective, than the proposed pulverized-coal plant. Presented evidence that IGCC is technically feasible and cost-competitive with pulverized coal.

Presidential Permits to Two Border Power Plants – Contested Air and Water Issues. Provided testimony on the air emissions and water consumption impact of two export power plants, Intergen and Sempra, in Mexicali, Mexico, and modifications necessary to minimize these impacts, including air emission offsets and incorporation of air cooling. These two plants are located within 3 miles of the California border, are interconnected only to the SDG&E transmission grid, and under the local control of the California Independent System Operator. Provided evidence that the CAISO had restricted the amount of power these two plants could export when commercial operation began in June 2003 to avoid unacceptable levels of transmission congestion on SDG&E's transmission system. The federal judge determined that the DOE had conducted an inadequate environmental assessment before issuing the Presidential Permits for these two plants and ordered the DOE to prepare a more comprehensive assessment.

300 MW Coal-Fired Circulating Fluidized Bed Boiler Plant - Best Available NO_x Control System. Provided testimony in dispute in case where approximately 50 percent NO_x control using selective non-catalytic reduction (SNCR) was accepted as BACT for a proposed 300 MW circulating fluidized bed (CFB) boiler plant in Kentucky. Presented testimony that SNCR was capable of continuous NO_x reduction of greater than 70 percent on a CFB unit and that low-dust, hot side selective catalytic reduction (SCR) and tail-end SCR were technically feasible and could achieve greater than 90 percent NO_x reduction.

Conversion of Existing Once-Through Cooled Boilers to Wet Towers, Parallel Wet-Dry Cooling, or Dry Cooling. Prepared preliminary design for the conversion of four natural gas and/or coal-fired utility boilers (Unit 4, 235 MW; Unit 3, 135 MW; Unit 2, 65 MW; and Unit 1,65 MW) from once-through river water cooling to wet cooling towers, parallel wet-dry cooling, and dry cooling. Major design constraints were available land for location of retrofit cooling systems and need to maintain maximum steam turbine backpressure at or below 5.5 inches mercury to match performance capabilities of existing equipment. Approach temperatures of 12 ^{o}F and 13 ^{o}F were used for the wet towers. SPX Cooling Technologies F-488 plume-abated wet cells with six feet of packing were used to achieve approach temperatures of 12 ^{o}F and 13 ^{o}F. Annual energy penalty of wet tower retrofit designs is approximately 1 percent. Parallel wet-dry or dry cooling was determined to be technically feasible for Unit 3 based on straightforward access to the Unit 3 surface condenser and available land adjacent to the boiler.

Utility Boiler – Assessment of Closed-Cycle Cooling Retrofit Cost for 1,200 MW Oil-Fired Plant. Prepared an assessment of the cost and feasibility of a closed-cycle wet tower retrofit for the 1,200 MW

Roseton Generating Station in New York. Determined that the cost to retrofit the Roseton plant with plume-abated closed-cycle wet cooling was well established based on cooling tower retrofit studies performed by the original owner (Central Hudson Gas & Electric Corp.) and subsequent regulatory agency critique of the cost estimate. Also determined that elimination of redundant and/or excessive budgetary line items in owners cost estimate brings the closed-cycle retrofit in line with expected costs for comparable new or retrofit plume-abated cooling tower applications. Closed-cycle cooling has been accepted as an issue that will be adjudicated.

2,000 MW Nuclear Power Plant – Closed-Cycle Cooling Retrofit Feasibility. Prepared assessment of the cost and feasibility of a closed-cycle wet tower retrofit for the 2,000 MW Indian Point Generating Station in New York. Determined that the most appropriate arrangement for the hilly site would be an inline plume-abated wet tower instead of the round tower configuration analyzed by the owner. Use of the inline configuration would allow placement of the towers at numerous sites on the property with little or need for blasting of bedrock, greatly reducing the cost of the retrofit. Also proposed an alternative circulating cooling water piping configuration to avoid the extensive downtime projected by the owner for modifications to the existing discharge channel.

Best Available NO_x Control System for 525 MW Coal-Fired Circulating Fluidized Bed Boiler Plant. Provided testimony in dispute over whether 50 percent NO_x control using selective non-catalytic reduction (SNCR) constituted BACT for a proposed 525 MW circulating fluidized bed (CFB) boiler plant in Pennsylvania. Presented testimony that SNCR was capable of continuous NO_x reduction of greater than 70 percent on a CFB unit and that tail-end selective catalytic reduction (SCR) was technically feasible and could achieve greater than 90 percent NO_x reduction.

Evaluation of Correlation Between Opacity and PM_{10} Emissions at Coal-Fired Plant. Provided testimony on whether correlation existed between mass PM_{10} emissions and opacity during opacity excursions at large coal-fired boiler in Georgia. EPA and EPRI technical studies were reviewed to assess the correlation of opacity and mass emissions during opacity levels below and above 20 percent. A strong correlation between opacity and mass emissions was apparent at a sister plant at opacities less than 20 percent. The correlation suggests that the opacity monitor correlation underestimates mass emissions at opacities greater than 20 percent, but may continue to exhibit a good correlation for the component of mass emissions in the PM_{10} size range.

Emission Increases Associated with Retrofit of SCR Existing Coal-Fired Units. Provided testimony in successful effort to compel an existing coal-fired power plant located in Massachusetts to meet an accelerated NO_x and SO_2 emission control system retrofit schedule. Plant owner argued the installation of advanced NO_x and SO_2 control systems would generate > 1 ton/year of ancillary emissions, such as sulfuric acid mist, and that under Massachusetts Dept. of Environmental Protection regulation ancillary emissions > 1 ton/year would require a BACT evaluation and a two-year extension to retrofit schedule. Successfully demonstrated that no ancillary emissions would be generated if the retrofit NO_x and SO_2 control systems were properly sized and optimized. Plant owner committed to accelerated compliance schedule in settlement agreement.

1,000 MW Coastal Combined-Cycle Power Plant – Feasibility of Dry Cooling. Expert witness in on-going effort to require use of dry cooling on proposed 1,000 MW combined-cycle "repower" project at site of an existing 1,000 MW utility boiler plant in central coastal California. Project proponent argued that site was two small for properly sized air-cooled condenser (ACC) and that use of ACC would cause 12-month construction delay. Demonstrated that ACC could easily be located on the site by splitting total of up to 80 cells between two available locations at the site. Also demonstrated that an ACC optimized for low height and low noise would minimize or eliminate proponent claims of negative visual and noise impacts.

CONTINUOUS EMISSION MONITOR (CEM) PROJECT EXPERIENCE

Process Heater CO and NO_x CEM Relative Accuracy Testing. Project manager and lead engineer for process heater CO and NO_x analyzer relative accuracy test program at petrochemical manufacturing facility. Objective of test program was to demonstrate that performance of onsite CO and NO_x CEMs was in compliance

with U.S. EPA "Boiler and Industrial Furnace" hazardous waste co-firing regulations. A TECO Model 48 CO analyzer and a TECO Model 10 NO_x analyzer were utilized during the test program to provide $\pm$1 ppm measurement accuracy, and all test data was recorded by an automated data acquisition system. One of the two process heater CEM systems tested failed the initial test due to leaks in the gas conditioning system. Troubleshooting was performed using O_2 analyzers, and the leaking component was identified and replaced. This CEM system met all CEM relative accuracy requirements during the subsequent retest.

Performance Audit of NO_x and SO_2 CEMs at Coal-Fired Power Plant. Lead engineer on system audit and challenge gas performance audit of NO_x and SO_2 CEMs at a coal-fired power plant in southern Nevada. Dynamic and instrument calibration checks were performed on the CEMs. A detailed visual inspection of the CEM system, from the gas sampling probes at the stack to the CEM sample gas outlet tubing in the CEM trailer, was also conducted. The CEMs passed the dynamic and instrument calibration requirements specified in EPA's Performance Specification Test - 2 (NO_x and SO_2) alternative relative accuracy requirements.

AIR ENGINEERING/AIR TESTING PROJECT EXPERIENCE – GENERAL

Reverse Air Fabric Filter Retrofit Evaluation – Coal-Fired Boiler. Lead engineer for upgrade of reverse air fabric filters serving coal-fired industrial boilers. Fluorescent dye injected to pinpoint broken bags and damper leaks. Corrosion of pneumatic actuators serving reverse air valves and inadequate insulation identified as principal causes of degraded performance.

Pulse-Jet Fabric Filter Performance Evaluation – Gold Mine. Lead engineer on upgrade of pulse-jet fabric filter and associated exhaust ventilation system serving an ore-crushing facility at a gold mine. Fluorescent dye used to identify bag collar leaks, and modifications were made to pulse air cycle time and duration. This marginal source was in compliance at 20 percent of emission limit following completion of repair work.

Pulse-Jet Fabric Filter Retrofit - Gypsum Calciner. Lead engineer on upgrade of pulse-jet fabric filter controlling particulate emissions from a gypsum calciner. Recommendations included a modified bag clamping mechanism, modified hopper evacuation valve assembly, and changes to pulse air cycle time and pulse duration.

Wet Scrubber Retrofit – Plating Shop. Project engineer on retrofit evaluation of plating shop packed-bed wet scrubbers failing to meet performance guarantees during acceptance trials, due to excessive mist carryover. Recommendations included relocation of the mist eliminator (ME), substitution of the original chevron blade ME with a mesh pad ME, and use of higher density packing material to improve exhaust gas distribution. Wet scrubbers passed acceptance trials following completion of recommended modifications.

Electrostatic Precipitator (ESP) Retrofit Evaluation – MSW Boiler. Lead engineer for retrofit evaluation of single field ESP on a municipal solid waste (MSW) boiler. Recommendations included addition of automated power controller, inlet duct turning vanes, and improved collecting plate rapping system.

ESP Electric Coil Rapper Vibration Analysis Testing - Coal-Fired Boiler. Lead engineer for evaluation of ESP rapper effectiveness test program on three field ESP equipped with "magnetically induced gravity return" (MIGR) rappers. Accelerometers were placed in a grid pattern on ESP collecting plates to determine maximum instantaneous plate acceleration at a variety of rapper power setpoints. Testing showed that the rappers met performance specification requirements.

Aluminum Remelt Furnace Particulate Emissions Testing. Project manager and lead engineer for high temperature (1,600 ^{o}F) particulate sampling of a natural gas-fired remelt furnace at a major aluminum rolling mill. Objectives of test program were to: 1) determine if condensable particulate was present in stack gases, and 2) to validate the accuracy of the in-stack continuous opacity monitor (COM). Designed and constructed a customized high temperature (inconel) PM_{10}/Mtd 17 sampling assembly for test program. An onsite natural gas-fired boiler was also tested to provide comparative data for the condensable particulate portion of the test program. Test results showed that no significant levels of condensable particulate in the remelt furnace exhaust

gas, and indicated that the remelt furnace and boiler had similar particulate emission rates. Test results also showed that the COM was accurate.

Aluminum Remelt Furnace CO and NO_x Testing. Project manager and lead engineer for continuous week-long testing of CO and NO_x emissions from aluminum remelt furnace. Objective of test program was to characterize CO and NO_x emissions from representative remelt furnace for use in the facility's criteria pollution emissions inventory. A TECO Model 48 CO analyzer and a TECO Model 10 NO_x analyzer were utilized during the test program to provide $\pm$1 ppm measurement accuracy, and all test data was recorded by an automated data acquisition system.

OIL AND GAS PRODUCTION AIR ENGINEERING/TESTING EXPERIENCE

Air Toxics Testing of Oil and Gas Production Sources. Project manager and lead engineer for test plan/test program to determine VOC removal efficiency of packed tower scrubber controlling sulfur dioxide emissions from a crude oil-fired steam generator. Ratfisch 55 VOC analyzers were used to measure the packed tower scrubber VOC removal efficiency. Tedlar bag samples were collected simultaneously to correlate BTX removal efficiency to VOC removal efficiency. This test was one of hundreds of air toxics tests performed during this test program for oil and gas production facilities from 1990 to 1992. The majority of the volatile air toxics analyses were performed at in-house laboratory. Project staff developed thorough familiarity with the applications and limitations of GC/MS, GC/PID, GC/FID, GC/ECD and GC/FPD. Tedlar bags, canisters, sorbent tubes and impingers were used during sampling, along with isokinetic tests methods for multiple metals and PAHs.

Air Toxics Testing of Glycol Reboiler – Gas Processing Plant. Project manager for test program to determine emissions of BTXE from glycol reboiler vent at gas processing facility handling 12 MM/cfd of produced gas. Developed innovative test methods to accurately quantify BTXE emissions in reboiler vent gas.

Air Toxics Emissions Inventory Plan. Lead engineer for the development of generic air toxics emission estimating techniques (EETs) for oil and gas production equipment. This project was performed for the Western States Petroleum Association in response to the requirements of the California Air Toxics "Hot Spots" Act. EETs were developed for all point and fugitive oil and gas production sources of air toxics, and the specific air toxics associated with each source were identified. A pooled source emission test methodology was also developed to moderate the cost of source testing required by the Act.

Fugitive NMHC Emissions from TEOR Production Field. Project manager for the quantification of fugitive Nonmethane hydrocarbon (NMHC) emissions from a thermally enhanced oil recovery (TEOR) oil production field in Kern County, CA. This program included direct measurement of NMHC concentrations in storage tank vapor headspace and the modification of available NMHC emission factors for NMHC-emitting devices in TEOR produced gas service, such as wellheads, vapor trunklines, heat exchangers, and compressors. Modification of the existing NMHC emission factors was necessary due to the high concentration of CO_2 and water vapor in TEOR produced gases.

Fugitive Air Emissions Testing of Oil and Gas Production Fields. Project manager for test plan/test program to determine VOC and air toxics emissions from oil storage tanks, wastewater storage tanks and produced gas lines. Test results were utilized to develop comprehensive air toxics emissions inventories for oil and gas production companies participating in the test program.

Oil and Gas Production Field – Air Emissions Inventory and Air Modeling. Project manager for oil and gas production field risk assessment. Project included review and revision of the existing air toxics emission inventory, air dispersion modeling, and calculation of the acute health risk, chronic non-carcinogenic risk and carcinogenic risk of facility operations. Results indicated that fugitive H_2S emissions from facility operations posed a potential health risk at the facility fenceline.

PETROLEUM REFINERY AIR ENGINEERING/TESTING EXPERIENCE

Criteria and Air Toxic Pollutant Emissions Inventory for Proposed Refinery Modifications. Project manager and technical lead for development of baseline and future refinery air emissions inventories for process modifications required to produce oxygenated gasoline and desulfurized diesel fuel at a California refinery. State of the art criteria and air toxic pollutant emissions inventories for refinery point, fugitive and mobile sources were developed. Point source emissions estimates were generated using onsite criteria pollutant test data, onsite air toxics test data, and the latest air toxics emission factors from the statewide refinery air toxics inventory database. The fugitive volatile organic compound (VOC) emissions inventories were developed using the refinery's most recent inspection and maintenance (I&M) monitoring program test data to develop site-specific component VOC emission rates. These VOC emission rates were combined with speciated air toxics test results for the principal refinery process streams to produce fugitive VOC air toxics emission rates. The environmental impact report (EIR) that utilized this emission inventory data was the first refinery "Clean Fuels" EIR approved in California.

Air Toxic Pollutant Emissions Inventory for Existing Refinery. Project manager and technical lead for air toxic pollutant emissions inventory at major California refinery. Emission factors were developed for refinery heaters, boilers, flares, sulfur recovery units, coker deheading, IC engines, storage tanks, process fugitives, and catalyst regeneration units. Onsite source test results were utilized to characterize emissions from refinery combustion devices. Where representative source test results were not available, AP-42 VOC emission factors were combined with available VOC air toxics speciation profiles to estimate VOC air toxic emission rates. A risk assessment based on this emissions inventory indicated a relatively low health risk associated with refinery operations. Benzene, 1,3-butadiene and PAHs were the principal health risk related pollutants emitted.

Air Toxics Testing of Refinery Combustion Sources. Project manager for comprehensive air toxics testing program at a major California refinery. Metals, Cr^{+6}, PAHs, H_2S and speciated VOC emissions were measured from refinery combustion sources. High temperature Cr^{+6} stack testing using the EPA Cr^{+6} test method was performed for the first time in California during this test program. Representatives from the California Air Resources Board source test team performed simultaneous testing using ARB Method 425 (Cr^{+6}) to compare the results of EPA and ARB Cr^{+6} test methodologies. The ARB approved the test results generated using the high temperature EPA Cr^{+6} test method.

Air Toxics Testing of Refinery Fugitive Sources. Project manager for test program to characterize air toxic fugitive VOC emissions from fifteen distinct process units at major California refinery. Gas, light liquid, and heavy liquid process streams were sampled. BTXE, 1,3-butadiene and propylene concentrations were quantified in gas samples, while BTXE, cresol and phenol concentrations were measured in liquid samples. Test results were combined with AP-42 fugitive VOC emission factors for valves, fittings, compressors, pumps and PRVs to calculate fugitive air toxics VOC emission rates.

LATIN AMERICA ENVIRONMENTAL PROJECT EXPERIENCE

Preliminary Design of Ambient Air Quality Monitoring Network – Lima, Peru. Project leader for project to prepare specifications for a fourteen station ambient air quality monitoring network for the municipality of Lima, Peru. Network includes four complete gaseous pollutant, particulate, and meteorological parameter monitoring stations, as well as eight PM_{10} and TSP monitoring stations.

Evaluation of Proposed Ambient Air Quality Network Modernization Project – Venezuela. Analyzed a plan to modernize and expand the ambient air monitoring network in Venezuela. Project was performed for the U.S. Trade and Development Agency. Direct interaction with policy makers at the Ministerio del Ambiente y de los Recursos Naturales Renovables (MARNR) in Caracas was a major component of this project.

Evaluation of U.S.-Mexico Border Region Copper Smelter Compliance with Treaty Obligations – Mexico. Project manager and lead engineer to evaluate compliance of U.S. and Mexican border region copper smelters with the SO_2 monitoring, recordkeeping and reporting requirements in Annex IV [Copper Smelters] of

the La Paz Environmental Treaty. Identified potential problems with current ambient and stack monitoring practices that could result in underestimating the impact of SO_2 emissions from some of these copper smelters. Identified additional source types, including hazardous waste incinerators and power plants, that should be considered for inclusion in the La Paz Treaty process.

Development of Air Emission Standards for Petroleum Refinery Equipment - Peru. Served as principal technical consultant to the Peruvian Ministry of Energy in Mines (MEM) for the development of air emission standards for Peruvian petroleum refineries. The sources included in the scope of this project included: 1) SO_2 and NO_x refinery heaters and boilers, 2) desulfurization of crude oil, particulate and SO_2 controls for fluid catalytic cracking units (FCCU), 3) VOC and CO emissions from flares, 4) vapor recovery systems for marine unloading, truck loading, and crude oil/refined products storage tanks, and 5) VOC emissions from process fugitive sources such as pressure relief valves, pumps, compressors and flanges. Proposed emission limits were developed for new and existing refineries based on a thorough evaluation of the available air emission control technologies for the affected refinery sources. Leading vendors of refinery control technology, such as John Zink and Exxon Research, provided estimates of retrofit costs for the largest Peruvian refinery, La Pampilla, located in Lima. Meetings were held in Lima with refinery operators and MEM staff to discuss the proposed emission limits and incorporate mutually agreed upon revisions to the proposed limits for existing Peruvian refineries.

Development of Air Emission Limits for ICE Cogeneration Plant - Panamá. Lead engineer assisting U.S. cogeneration plant developer to permit an ICE cogeneration plant at a hotel/casino complex in Panama. Recommended the use of modified draft World Bank NO_x and PM limits for ICE power plants. The modification consisted of adding a thermal efficiency factor adjustment to the draft World Bank NO_x and PM limits. These proposed ICE emission limits are currently being reviewed by Panamanian environmental authorities.

Mercury Emissions Inventory for Stationary Sources in Northern Mexico. Project manager and lead engineer to estimate mercury emissions from stationary sources in Northern Mexico. Major potential sources of mercury emissions include solid- and liquid-fueled power plants, cement kilns co-firing hazardous waste, and non-ferrous metal smelters. Emission estimates were provided for approximately eighty of these sources located in Northern Mexico. Coordinated efforts of two Mexican subcontractors, located in Mexico City and Hermosillo, to obtain process throughput data for each source included in the inventory.

Translation of U.S. EPA Scrap Tire Combustion Emissions Estimation Document – Mexico. Evaluated the Translated a U.S. EPA scrap tire combustion emissions estimation document from English to Spanish for use by Latin American environmental professionals.

Environmental Audit of Aluminum Production Facilities – Venezuela. Evaluated the capabilities of existing air, wastewater and solid/hazardous waste control systems used by the aluminum industry in eastern Venezuela. This industry will be privatized in the near future. Estimated the cost to bring these control systems into compliance with air, wastewater and solid/hazardous waste standards recently promulgated in Venezuela. Also served as technical translator for team of U.S. environmental engineers involved in the due diligence assessment.

Assessment of Environmental Improvement Projects – Chile and Peru. Evaluated potential air, water, soil remediation and waste recycling projects in Lima, Peru and Santiago, Chile for feasibility study funding by the U.S. Trade and Development Agency. Project required onsite interaction with in-country decisionmakers (in Spanish). Projects recommended for feasibility study funding included: 1) an air quality technical support project for the Santiago, Chile region, and 2) soil remediation/metals recovery projects at two copper mine/smelter sites in Peru.

Air Pollution Control Training Course – Mexico. Conducted two-day Spanish language air quality training course for environmental managers of assembly plants in Mexicali, Mexico. Spanish-language course manual prepared by Powers Engineering. Practical laboratory included training in use of combustion gas analyzer, flame ionization detector (FID), photoionization detector (PID), and occupational sampling.

Renewable Energy Resource Assessment Proposal – Panama. Translated and managed winning bid to evaluate wind energy potential in Panama. Direct interaction with the director of development at the national utility monopoly (IRHE) was a key component of this project.

Comprehensive Air Emissions Testing at Assembly Plant – Mexico. Project manager and field supervisor of emissions testing for particulates, NO_x, SO_2 and CO at turbocharger/air cooler assembly plant in Mexicali, Mexico. Source specific emission rates were developed for each point source at the facility during the test program. Translated test report into Spanish for review by the Mexican federal environmental agency (SEMARNAP).

Air Pollution Control Equipment Retrofit Evaluation – Mexico. Project manager and lead engineer for comprehensive evaluation of air pollution control equipment and industrial ventilation systems in use at assembly plant consisting of four major facilities. Equipment evaluated included fabric filters controlling blast booth emissions, electrostatic precipitator controlling welding fumes, and industrial ventilation systems controlling welding fumes, chemical cleaning tank emissions, and hot combustion gas emissions. Recommendations included modifications to fabric filter cleaning cycle, preventative maintenance program for the electrostatic precipitator, and redesign of the industrial ventilation system exhaust hoods to improve capture efficiency.

Comprehensive Air Emissions Testing at Assembly Plant – Mexico. Project manager and field supervisor of emissions testing for particulates, NO_x, SO_2 and CO at automotive components assembly plant in Acuña, Mexico. Source-specific emission rates were developed for each point source at the facility during the test program. Translated test report into Spanish.

Fluent in Spanish. Studied at the Universidad de Michoacán in Morelia, Mexico, 1993, and at the Colegio de España in Salamanca, Spain, 1987-88. Have lectured (in Spanish) on air monitoring and control equipment at the Instituto Tecnológico de Tijuana. Maintain contact with Comisión Federal de Electricidad engineers responsible for operation of wind and geothermal power plants in Mexico, and am comfortable operating in the Mexican business environment.

PUBLICATIONS

Bill Powers, "*San Diego Smart Energy 2020 – The 21st Century Alternative*," San Diego, October 2007.

Bill Powers, "*Energy, the Environment, and the California – Baja California Border Region*," Electricity Journal, Vol. 18, Issue 6, July 2005, pp. 77-84.

W.E. Powers, *"Peak and Annual Average Energy Efficiency Penalty of Optimized Air-Cooled Condenser on 515 MW Fossil Fuel-Fired Utility Boiler,"* presented at California Energy Commission/Electric Power Research Institute Advanced Cooling Technologies Symposium, Sacramento, California, June 2005.

W.E. Powers, R. Wydrum, P. Morris, *"Design and Performance of Optimized Air-Cooled Condenser at Crockett Cogeneration Plant,"* presented at EPA Symposium on Technologies for Protecting Aquatic Organisms from Cooling Water Intake Structures, Washington, DC, May 2003.

P. Pai, D. Niemi, W.E. Powers, *"A North American Anthropogenic Inventory of Mercury Emissions,"* to be presented at Air & Waste Management Association Annual Conference in Salt Lake City, UT, June 2000.

P.J. Blau and W.E. Powers, *"Control of Hazardous Air Emissions from Secondary Aluminum Casting Furnace Operations Through a Combination of: Upstream Pollution Prevention Measures, Process Modifications and End-of-Pipe Controls,"* presented at 1997 AWMA/EPA Emerging Solutions to VOC & Air Toxics Control Conference, San Diego, CA, February 1997.

W.E. Powers, et. al., *"Hazardous Air Pollutant Emission Inventory for Stationary Sources in Nogales, Sonora, Mexico ,"* presented at 1995 AWMA/EPA Emissions Inventory Specialty Conference, RTP, NC, October 1995.

W.E. Powers, *"Develop of a Parametric Emissions Monitoring System to Predict NO_x Emissions from Industrial Gas Turbines,"* presented at 1995 AWMA Golden West Chapter Air Pollution Control Specialty Conference, Ventura, California, March 1995.

W. E. Powers, et. al., *"Retrofit Control Options for Particulate Emissions from Magnesium Sulfite Recovery Boilers,"* presented at 1992 TAPPI Envr. Conference, April 1992. Published in *TAPPI Journal*, July 1992.

S. S. Parmar, M. Short, W. E. Powers, *"Determination of Total Gaseous Hydrocarbon Emissions from an Aluminum Rolling Mill Using Methods 25, 25A, and an Oxidation Technique,"* presented at U.S. EPA Measurement of Toxic and Related Air Pollutants Conference, May 1992.

N. Meeks, W. E. Powers, *"Air Toxics Emissions from Gas-Fired Internal Combustion Engines,"* presented at AIChE Summer Meeting, August 1990.

W. E. Powers, *"Air Pollution Control of Plating Shop Processes,"* presented at 7th AES/EPA Conference on Pollution Control in the Electroplating Industry, January 1986. Published in *Plating and Surface Finishing* magazine, July 1986.

H. M. Davenport, W. E. Powers, *"Affect of Low Cost Modifications on the Performance of an Undersized Electrostatic Precipitator,"* presented at 79th Air Pollution Control Association Conference, June 1986.

AWARDS

Engineer of the Year, 1991 – ENSR Consulting and Engineering, Camarillo
Engineer of the Year, 1986 – Naval Energy and Environmental Support Activity, Port Hueneme
Productivity Excellence Award, 1985 – U. S. Department of Defense

PATENTS

Sedimentation Chamber for Sizing Acid Mist, Navy Case Number 70094

STATE OF CALIFORNIA

Energy Resources Conservation and Development Commission

In the Matter of: APPLICATION FOR CERTIFICATION FOR THE PALEN SOLAR POWER PROJECT	DOCKET NO. 09-AFC-7

INTERVENOR CENTER FOR BIOLOGICAL DIVERSITY

Testimony of Ileene Anderson

Re: Impacts to Sensitive Plants and Wildlife from the Proposed Palen Solar Power Project

Docket 09-AFC-7

Summary of Testimony

The proposed project will be detrimental to numerous rare species. In some instances the Revised Staff Assessment (RSA) fails to evaluate the presence of rare species and identify impacts. Elsewhere, the RSA fails to adequately avoid, minimize and mitigate the impacts to these rare species as required under CEQA (and NEPA).

The proposed project in itself as well as in conjunction with other cumulative projects will further imperil already rare species driving them closer to extinction and will result in the need for additional species to be safeguarded under Endangered Species Act protection.

Qualifications

My qualifications are provided on my Resume attached to this Testimony and as discussed below.

I have over 20 years of experience in identifying, surveying for and documenting biological resources in southern California, including the Mojave desert.

I have a Master's of Science in Biology and a Bachelor's of Arts in Biology from the California State University, Northridge. I have continuing education in restoration/revegetation/reclamation of native habitats at the University of California, Riverside.

I have directed and participated in numerous field surveys for federal- and state-listed threatened and endangered species, as well as other rare and common species. I have written results in conformance with the California Environmental Quality Act and the National Environmental Policy Act.

I have written, implemented and monitored a variety of restoration and revegetation plans, primarily implemented as mitigation.

I have published articles on these subjects in peer-reviewed scientific journals and presented papers/posters at scientific meetings.

I have provided expert testimony on plant and animal issues at State Water Resources Control Board, California Public Utilities Commission and the California Energy Commission hearings.

I was a two-term federal appointee to the BLM's California Desert Advisory Council representing renewable resources, and served one year as chairperson.

I am currently a staff biologist with the Center for Biological Diversity, where I focus on native natural resource issues primarily in southern California, including desert regions of Riverside County.

Statement

After my review of the biological sections of the RSA, I agree that the project as proposed would have major impacts to the biological resources in the Chuckwalla Valley, affecting sensitive plant and wildlife species and eliminating a broad expanse of relatively undisturbed Coloradan Desert habitat (RSA at C.2-1). However, my conclusion is that the RSA fails to adequately identify all of the on-site resources, evaluate the impacts to those resources and propose adequate mitigation. Typically a project of this size would involve many seasons of surveys to thoroughly document all of the resources that occur on the site. Multiple years of surveys are particularly important in the desert because of the unpredictable and variable precipitation patterns. Failure to conduct sufficient surveys prior to construction of the project also effectively eliminates the most important function of surveys - using the information from the surveys to avoid and minimize harm caused by the project and reduce the need for mitigation. Often efforts to mitigate harm are far less effective than preventing the harm in the first place. In addition, without understanding the scope of harm before it occurs, it is difficult to quantify an appropriate amount and type of mitigation.

Overarching Issues

The generalized strategy of 1:1 mitigation for desert tortoise habitat is proposed to mitigate a multitude of other species – golden eagles, migratory/special status species birds, bats, badger, kit fox, and rare plants. While the Revised Staff Assessment (RSA) requires that acquired mitigation lands must be habitat for these impacted species, because that habitat is already inhabited by the same species for which mitigation is sought, this mitigation strategy ensures a *net decrease* in habitat for impacted species. To actually provide mitigation that staunches species' habitat losses, the ratio must be higher than 1:1[1]. I recommend a *minimum* 2:1 mitigation is more appropriate to assure, not only that the project impacts are mitigated appropriately but that the net losses of habitat for rare species are stopped. This strategy is essential to prevent future listings under Endangered Species Acts – both state and federal.

Many of the plans that are proposed by staff to adequately minimize or mitigate impacts are either not provided in the RSA or anywhere else or are draft plans that lack specific details in order to evaluate their effectiveness. Therefore it is impossible for me to evaluate or determine the efficacy of proposed minimization and mitigation to actually adequately mitigate impacts. While I recognize that the regulatory agencies have the responsibility of assuring that mitigation meets all the LORS and conditions, I have not always found that to be the case. Studies of mitigation compliance have borne this out as well.[2] Making all of the plans available as part of the public process is important to assure the public that their public resources are being protected – without public disclosure of these plans during the process there is no way to evaluate whether the Commission has put in place adequate plans to prevent degradation of our natural heritage, clean air and water. I recommend that the Commission put in place a public process that enables public input on the plethora of "mitigation" plans that are being proposed as conditions of certification for this (and other) proposed projects.

I discuss additional species specific issues below.

Desert Tortoise

I recognize that little recent desert tortoise sign was found on the proposed project site, and desert tortoise, if present currently, are likely to inhabit the site at very low densities. The project site it located in the Eastern Colorado Recovery Unit of the desert tortoise – a recovery unit that is in steep decline, having population decreases of 37% between 2005 and 2007[3], which is the most recent data publicly available. This decline is has occurred over ten years *after* the species was placed under Endangered Species Act protection.

If desert tortoise are found on the proposed project site, the proposal is to move any desert tortoise through relocation or translocation. The most recent report on desert

[1] Moilen et al. 2009, Norton 2009
[2] Ibid.;
[3] USFWS 2009

tortoise translocations document[4] an unacceptable 44% confirmed mortality of translocated desert tortoise since the translocation occurred 2008 and the last surveys in 2009. Thirty-five additional tortoises (22%) were "missing" – status unknown. Coupled with that, all translocated tortoise had tested negative for deadly diseases prior to being translocated, but post-translocation, 11% tested positive setting up a tragic epidemiological situation.

As part of the Desert Renewable Energy Conservation Plan (DRECP), an Independent Science Advisor committee was convened, and they have recently produced Draft Recommendations for the DRECP. In that document they state "One action that we generally do ***not*** endorse as mitigation per se—except perhaps under certain rare circumstances where scientific evidence suggests it may be warranted—is animal translocations out of proposed development areas into reserve areas. This is often done but rarely effective—a "feel-good" measure that has dubious ecological benefits and potential to do more harm than good."[original emphasis][5].

Because so many of the proposed mitigations for badger, kit fox and other species depend upon "passive relocation" or translocations and the lack of evaluation of impacts from these types of activities in the RSA,I believe a re-evaluation of impacts needs to be included in a supplemental environmental review.

The Independent Science Advisors also offer a desert tortoise specific recommendation - "As with the Mohave ground squirrel, the advisors do ***not*** recommend translocation of desert tortoise as effective mitigation or conservation action, in part because translocated tortoises suffer high mortality rates" [original emphasis] [6]. This important recommendation is additionally noteworthy because the two desert tortoise advisors, were both independent researchers on the Fort Irwin translocation effort, as well as other translocations. Their recommendation strongly suggests that translocation may do more harm than good.

Despite all of the bad news about translocation for desert tortoise and against the recommendations of the independent science advisors to the DRECP, one of the conditions of certification (Bio – 10) requires only that a translocation and relocation plan be developed in the future. The desert tortoise translocation plan is not finalized and areas have not been identified for translocation. Based on the existing draft plan (DR-BIO-55) which no longer complies with the most recent guidelines from USFWS[7], it is very unclear to me how successful this proposal will be.

Because a final translocation plan or even a revised draft translocation plan has not been provided, there is no way for me to comment on it. However, from the information that was provided several concerns arise. For example, long-term monitoring of relocated desert tortoise is virtually absent from the Draft Desert Tortoise

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[4] Gowan and Berry 2009.
[5] ISA 2010 at pg. 75
[6] Ibid at pg. 77.
[7] USFWS 2010

Translocation Plan. Because of the poor track record of successful relocation/translocation of desert tortoise[8], long-term post-relocation monitoring is essential to fully evaluate the success of any relocation effort.

In order to assure that any relocated desert tortoises do not have to be moved subsequently as avoidance and mitigation for other projects, safeguards must be put in place to preserve lands onto which any animals are relocated/translocated and the conditions of certification need to include this important concept.

Specifically regarding Bio-9 (1), the desert tortoise fencing along Interstate 10 needs to be installed prior to any desert tortoise relocation or translocation. Desert tortoises are known to make long distance movements after being moved and having a fence in place may help to minimize mortality.

While the RSA recognizes that the proposed project and reconfigured alternatives fall within a Northern and Eastern Colorado Plan (NECO) designated Wildlife Habitat Management Area (WHMA), it does not discuss that the area is specified for Desert Wildlife Management Area (DWMA) *connectivity*. Because the propose project and reconfigured alternatives are not only in desert tortoise habitat, but within a WHMA and WHMA for DWMA connectivity[9], the proposed 1:1 mitigation is inadequate. As stated above 1:1 mitigation ratio is not generally appropriate, even for impacts to currently unoccupied desert tortoise habitat, in this instance, the 1:1 ratio is particularly inappropriate because it does not take into consideration the importance of this specific location in the WHMA for DWMA connectivity as identified in the NECO plan. Therefore, at minimum, a 2:1 mitigation ratio needs to be implemented to truly off-set the impacts to this important linkage zone.

Despite the cumulative impacts analysis for desert tortoise, I fail to see how the proposed conditions of certifications guarantee adequate compensation for the impacts to this identified connectivity. The project is proposed in an identified linkage area for desert tortoise as per the NECO plan[10], yet the mitigation relies on "probable" linkages (RSA at C.2-177). The nearest "probable" linkage (RSA at Biological Resources Figure 6) includes another proposed large-scale industrial solar project – Desert Sunlight, which has a DEIS currently out for public review.

The RSA generally fails to recognize that based on the current desert tortoise recovery plan[11], the project is located in the *eastern* Colorado recovery unit. Instead, the analysis uses a *draft* revision of the desert tortoise recovery plan's scheme which "lumped" two currently distinct recovery units - the eastern Colorado and the northern Colorado recovery units - into a single unit – the Colorado recovery unit. However more recent data indicate that the two recovery units in the current recovery plan are

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[8] Gowan and Berry 2009
[9] NECO Map 2-21
[10] Ibid
[11] USFWS 1994.

genetically unique and fully justifiable[12]. The conditions of certification do not require that mitigation lands be in the eastern Colorado recovery unit, but instead include the much larger and genetically different northern Colorado recovery unit. In my mind, this also undermines the efficacy of the proposed mitigation and fails to fully mitigate the impacts to the unique genetic type of desert tortoise found in the eastern Colorado recovery unit.

Recent science indicates that canid predation affects both resident, control and translocated desert tortoises[13]. While the minimization measures that are proposed for reducing some predators on the proposed project site and reconfigured alternatives, the new and best available science needs to be incorporated into the Conditions of Certification for this (and other projects). Ravens, another human subsidized predator in the desert, have also been identified as predators on desert tortoises. The Conditions of Certification require that payment be made to support the USFWS Regional Raven Management Program (Bio 13(2)). The CEC or CDFG should set up and implement a similar program to address the regional canid management in support of reducing predation of desert tortoises (and other rare animals) and that payment in support of that program also be required as a Condition of Certification.

Sand Dune Community/Mojave Fringe-toed Lizard

Bio-20 lays out criteria for compensation lands that in my opinion do not accurately mitigate the impacts to the Mojave fringe-toed lizard. This species has naturally disjunct habitat areas and reaches its southern-most range in the general vicinity of the project site. While the Mojave fringe-toed lizards require Aeolian sands and sandy substrate on which to live[14], *its entire* habitat needs to be mitigated at a 3:1 mitigation ratio including habitat that is affected by indirect impacts.

I agree with the Revised staff assessment in the cumulate analysis that 'Staff believes that by requiring the Applicant to acquire and preserve habitat within the Chuckwalla Valley dune system, at a ratio of 3:1, fragmentation from anticipated future development of private lands can be minimized by protecting, in perpetuity, these lands from future development. (RSA at C.2-181). All Mojave fringe-toed lizard habitat should be mitigated at such a level.

I found it very confusing and unclear how Bio-20 in the RSA relates to the information provided in the Data Requests of July 9, 2010. It is unclear if "high quality MFTL habitat" equates to "Zone 2 MFTL habitat" or how that relates to the *occupancy* of the lizards identified during surveys in those areas or the areas identified in the RSA as "stabilized and partially stabilized sand dunes", "non-dune Mojave fringe-toed lizard habitat". Because the focus of impact analysis and subsequent mitigation should be on the Mojave fringe-toed lizard, it is my opinion that how the habitat is affected by the impact of the project and the impact to the sand transport corridor are all direct impacts to

[12] Murphy et al. 2007
[13] Esque et al. 2010
[14] Barrows 1997.

Mojave fringe-toed lizard habitat and should be mitigated as such. Therefore, all impacts to Mojave fringe-toed lizard habitat should be mitigated at 3:1.

Birds

Curiously the RSA dismisses recognized avian attractants such as evaporation ponds and agricultural fields as not occurring in the vicinity of the project (RSA at C.2-11). However, the proposed project is currently designed to have 2 four-acre evaporation ponds or a total of 8 acres of ponds (RSA at C.2-119) and is directly adjacent to agricultural fields (RSA at Appendix C, Figure 5 through 8). The RSA notes that ravens, "waterfowl, shorebirds and other resident or migratory birds that drink or forage at the ponds" (RSA at C.2-119). While Bio- 26 proposes netting and monitoring of the evaporation ponds, their presence will still likely attract birds to the general area, even if subsequently the birds are not able to directly access the ponds. The RSA fails to quantitatively evaluate the impact to birds based on the McCrary[15] results, which estimated 1.7 birds deaths per week on a 32 ha site – a site fifty times smaller than the proposed 1,600+ ha solar facility. Other data are available on injury and mortality associated with reflective surfaces and powerlines[16] which could have been used to evaluate impacts to birds. While avian point counts were done in 2009, these data are not folded into an analysis of the potential impacts to birds from attraction onto the site by the proposed evaporation ponds and subsequent mortality occurring from collisions with mirrors or powerlines. While Bio-16 requires monitoring, which I support, the RSA still fails to analyze the potential impact which in my opinion may be significant.

Burrowing Owl

I agree with the RSA that the fate of passively relocated burrowing owls is undocumented and concerning (RSA at pg. C.2-109). Therefore I was surprised to find that Bio-18 (burrowing owl mitigation requirements) failed to require long-term monitoring of passively relocated burrowing owls. While burrowing owls were documented as occurring on the project site, the RSA failed to evaluate the potential impacts to the owls in the context of the regional population. Burrowing owls populations in the eastern deserts are documented to be at low densities[17]. Data are available on burrowing owls in eastern Riverside County from the California Burrowing Owl Survey – 2006-2007[18].

The remaining stronghold for burrowing owls in California – the Imperial Valley – has had a recently documented decline of 27% in the past 2 years[19], resulting in an even more dire state for burrowing owls in California. Because burrowing owls are in decline throughout California, and now their "stronghold" is documented to be declining severely, it is my opinion that the burrowing owls on this proposed project site and

[15] McCrary 1986
[16] Klem 1990, Erickson et al. 2005
[17] Wilderson and Siegel 2010.
[18] IBP 2009.
[19] Manning 2009.

reconfigured alternatives (and on other renewable energy projects) become even more important to species conservation efforts. While I support the acquisition of habitat specifically for burrowing owls as identified in the RSA, I think the mitigation of only 78 acres for 4 owls is too low, especially in the Colorado desert, as it is outdated agency guidance. Mean burrowing owl foraging territories are 242 hectares in size, although foraging territories for owl in heavily cultivated areas is only 35 hectares[20]. Regardless, the acquisition of only 78 acres (31.5 hectares) fails to mitigate for one bird even if it was relying on a heavily cultivated area. Therefore, it is my opinion that additional mitigation acreage needs to be required – calculated using the mean foraging territory size times the number of owls. This calculation results in 968 hectares (2,391 acres). I note that using the average foraging territory size for mitigation calculations may not accurately predict the carrying capacity and may *overestimate* the carrying capacity of the impacted site, since the proposed project site at 4,024 acres only support 4 birds – it may be that in this area of the Colorado desert 4,000+ acres is necessary to support 4 burrowing owls. While the RSA relied on guidance from CDFG from 2003, that guidance is now out of date in light of identified population declines[21], a more thorough census of burrowing owls throughout the state[22] and additional research on the species habitat[23]. Lastly, because the carrying capacity is tied to habitat quality, I recommend that language be included that mitigation lands that are acquired for burrowing owl be native habitats on undisturbed lands, not cultivated lands, which are subject to the whims of land use changes. I believe the long-term persistence of burrowing owls lie in their ability to utilize natural landscapes, not human-created ones.

Insects

Sand dune habitats are notorious for supporting endemic insects, typically narrow habitat specialists[24]. The RSA completely fails to address insects on the proposed project site. While the Center has brought this issue up on our comments on the Staff Assessment, the RSA brushes off this important issue by characterizing the impact to the sand dune community without actually requiring insect surveys. Absent the surveys clearly no evaluation of impacts to rare insects can be evaluated.

Special Status Plants

While I support late-season botanical surveys, these types of surveys should have been done prior to the assessment of impacts from the proposed project. As stated above, failure to conduct sufficient surveys prior to construction of the project effectively eliminates the most important function of surveys - using the information from the surveys to avoid and minimize harm caused by the project and reduce the need for mitigation. Often efforts to mitigate harm are far less effective than preventing the harm in the first place.

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[20] USFWS 2003
[21] Manning 2009
[22] Wilkerson and Siegel 2010
[23] USFWS 2003
[24] Dunn 2005.

Habitat Loss and Compensatory Mitigation

For many of the rare wildlife species, "Bio-12" is proposed as the mitigation for impacts. "Bio-12" is focused on compensatory mitigation for desert tortoise through the acquisition and conservation of a variety of number of acres based on different impact scenarios. While I support mitigation for desert tortoise, the mitigation measure needs to require that the mitigation actually benefit the other rare animals – just as it states for state jurisdictional water, where at least 608 acres of waters must be acquired.

Even with rare species occurring on the mitigation lands, the Commission must still recognize that the proposed project is a net loss of occupied habitat and possibly individuals of these species.

Cryptobiotic Soils

Cryptobiotic soils are an essential component in arid ecosystems to prevent desertification and perform a myriad of ecological functions including soil stability, porosity and water retention[25]. They stabilize soils and prevent erosion, decreasing fugitive dust[26]. They are easily disturbed and slow to regenerate[27]. Despite comments on the Staff Assessment requesting an evaluation of where the cryptobiotics were on the proposed project site and an analysis of the impacts of the project on these important soils, the RSA failed to do so. It is my opinion that the disturbance of these types of soil crusts will greatly increase many factors that will affect the nearby ecological functions including increased amount of PM-10 emissions from the proposed project site, alteration in hydrology and water retention among many other aspects. The final staff assessment must estimate the impact to these essential components of the landscape.

Fire Threats

Fire in desert ecosystems is well documented to cause catastrophic landscape scale changes[28] and impacts to the local species[29]. While the FSA mentions the impacts of fire via the proliferation of non-native weeds (RSA at pg. C.2-18 through 19, and many other places), it fails to adequately analyze the impacts of this issue for this proposed project that routinely relies on superheated liquids. It fails to adequately analyze the impact that a fire could have on the natural lands adjacent to the project site if it escaped from the site or address the mitigation of this impact. Instead it defers it to the Worker Environmental Awareness Program (WEAP) and only requires "a discussion of fire prevention measures to be implemented by workers during project activities" (RSA at

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[25] Belnap 2006,
[26] Belnap 2001
[27] Belnap and Eldridge 2001.
[28] Brown and Minnich 1986, Lovich and Bainbridge 1999, Brooks 2000, Brooks and Draper 2006, Brooks and Minnich 2007
[29] Ducher 2009.

pg. C.2-258). A fire prevention and protection plan needs to be required to preclude the escape of fire onto the adjacent landscape (avoidance), lay out clear guidelines for protocols if the fire does spread to adjacent wildlands (minimization) and a revegetation plan if fire does occur on adjacent lands originating from the project site (mitigation) or caused by any activities associated with construction or operation of the site even if the fire originates off of the project site.

Conclusions

I would like to summarize my conclusions as follows:

Despite some avoidance, minimization, and mitigation for the identified rare species, the project will still result in a net loss of habitat for many rare and common species and crucial connectivity for the desert tortoise. The RSA still fails to evaluate many very important biological issues. Therefore I find the review of impacts and suggested mitigations to be unsatisfactory. Without basic information about the use of the area by a variety of wildlife, plants and cryptobiotic soils it is impossible to assess the extent of the impacts to species populations in this area from the proposed project or reconfigurations.

The documents seem to indicate that the staff believes that all the potential plant and wildlife impacts can be resolved by simply purchasing land elsewhere suitable for the desert tortoise. While desert tortoise habitat acquisition and protection in other areas is an essential keystone of mitigation for the loss of habitat at the proposed project site, it does not and cannot mitigate for the loss of habitat of other species if their habitat does not occur on the compensation lands.

I suggest that field studies be initiated on any proposed compensation lands to assure that proper habitat is acquired to help mitigate impacts. Absent any real information in the field, any suggested mitigation or perceived impacts are pure conjecture. I also suggest that the missing field studies be conducted by knowledgeable researchers on the project site to fill in the missing data gaps which are the basis for analyzing impacts.

In summary, I find the document to be lacking as it pertains to biological resources. These deficiencies need to be addressed and remedied before in a revision to the SA or other environmental documentation prior to project permitting.

Declaration of Ileene E. Anderson

Re: Impacts to Sensitive Plants and Wildlife from the Proposed Palen Solar Power Project

Docket 09-AFC-7

I, Ileene Anderson, declare as follows:

1) I am currently a biologist for the Center for Biological Diversity. I have worked with the organization for five years.

2) My relevant professional qualifications and experience are set forth in the attached resume and the attached testimony and are incorporated herein by reference.

3) I prepared the testimony attached hereto and incorporated herein by reference, relating to the impacts of the proposed project on wildlife and plants.

4) I prepared the testimony attached hereto and incorporated herein by reference relating to the proposed Palen Solar Power Project in the Chuckwalla Valley in Riverside County.

5) It is my professional opinion that the attached testimony is true and accurate with respect to the issues that is addressed.

6) I am personally familiar with the facts and conclusions described within the attached testimony and if called as a witness, I could testify competently thereto.

I declare under penalty of perjury that the foregoing is true and correct to the best of my knowledge and belief.

Dated: October 6, 2010 Signed: _

At: Los Angeles, California

Curriculum Vitae
For
Ileene Anderson

Education

- M.S. with Distinction, Biology, California State University, Northridge, 1992
- B.A. Cum Laude, Biology, California State University, Northridge, 1989
- A.S. with Honors, Electronics, Bakersfield College, 1981

Professional Experience

2005 – present

Biologist and Public Lands Desert Director with the non-profit Center for Biological Diversity. Provide scientific expertise necessary for the conservation of California's internationally recognized unique flora and fauna in a variety of public and private land use arenas. My primary projects focus on central and southern California, including the California deserts, Tejon Ranch, Santa Ana River issues, Santa Clara River issues and numerous projects that occur within their watersheds. I comment on California Environmental Quality Act and/or National Environmental Policy Act, write petitions for plant and animal protection under the federal and state Endangered Species Act, provide scientific expertise for lawsuit settlement agreements, do public/media relations, and organize volunteers for a variety of conservation issues.

1997- 2005

Southern California Regional Botanist for the non-profit California Native Plant Society (CNPS). Provided scientific expertise necessary for the conservation of California's unique vegetation types in a variety of public and private land use plans, including the Four Southern California Forests Updated Land Use Management Plan, the West Mojave Habitat Conservation Plan, the West Riverside Multiple Species Habitat Conservation Plan, the Northern and Eastern Colorado Desert Plan, the Northern and Eastern Mojave Desert Plan, and many other smaller planning efforts. I have commented on hundreds of California Environmental Quality Act and/or National Environmental Policy Act documents, written petitions for plant protection under the federal Endangered Species Act, provided scientific expertise for lawsuit settlement agreements, done public relations in both print and radio, ran CNPS internal consensus building meetings, and organized volunteers for a variety of conservation and fund-raising issues.

1995 – 2005

Consultant on a variety of botanical projects, including rare plant surveys, quantitative and qualitative vegetation community characterization, restoration plans, vegetation monitoring and weed surveys. Project locations comprise a variety of plant communities in southern/central California including riparian, coastal sage scrub, alluvial fan scrub, alkali meadows, chaparral, and a variety of desert scrubs. A full list of projects is available upon request.

1996 – 1999

Part-time instructor at College of the Canyons (community college in Valencia, California). Courses included Introductory Biology for majors (Organismal/Environmental and Cellular/Molecular), Current Topics in Environmental Biology, and Botany. I also developed a course in Economic Botany.

1992 – 1995

Lead Botanist for The Chambers Group (an environmental consulting firm). Projects for which I was responsible included mapping, inventories, and rare plant surveys, which were written in compliance with NEPA and/or CEQA guidelines, including impact analysis and mitigation. This information was typically included in Biological Assessments (BAs), Environmental Assessments (EAs), Environmental Impact Reports (EIRs) or Environmental Impact Statements (EISs). Supervisory duties included coordinating two other botanists. Project management was also part of my duties.

1990 – 1994

Sales Associate at the Theodore Payne Foundation. This part-time job primarily included helping customers select appropriate native plant material for their gardens. Other duties included propagation and transplantation of native plant species.

2733 Cardwell Place, Los Angeles, CA 90046-1201
Phone: 323/848-7946 FAX: 323/650-4620 e-mail: ieanderson@roadrunner.com

1990-1992

Herbarium Curatorial Assistant at Rancho Santa Ana Botanic Gardens. Herbarium specimen mounting and curation from international collections was the primary responsibility.

Professional Courses/Seminars

Methods of Habitat Restoration - University of California, Riverside, Winter 1993
Desert Restoration - SERCAL, October 1993
Habitat Restoration Evaluation - University of California, Riverside, Winter 1994
Basic Wetlands Delineation - Wetland Training Institute, Inc. November 1995
Mycorrhizae in Habitat Restoration - University of California, Riverside, Winter 1995
Soils Workshop – Natural Resources Conservation Service, November 1998
Plant Community Characterization and Series Identification– Native Plant Society, June 1999
Statistical Analysis for the Modified Whittaker Plot – Colorado State University, August 2002

Professional Affiliations

BLM California Desert Advisory Council - Appointee Representing Renewable Resources (Chairperson 2001) from 1996-2002
California Botanical Society
California Native Plant Society – Conservation Committee; Legal Committee.
Friends of the Santa Clara River – Director at Large
Rancho Santa Ana Botanic Gardens – Research Associate.
Society for Ecological Restoration – Coastal Sage Scrub Guild Co-coordinator (1995-2001)
Southern California Botanists – Director at Large (1994-2002)

Expert Witness

State Water Resources Control Board – May 2007 – Testified on Santa Ana River plant and animal issues.
California Public Utilities Commission – March 2008 – Testified on plant issues for Sunrise Powerlink Project.
California Energy Commission – January 2010 – Testified on rare animal and plant issues for Ivanpah Solar Electric Generating System

Publications and Posters

Dickey, John, Maurice Hall, Mark Madison, Jason Smesrud, Margot Griswold, Quitterie Cotten, Mica Heilmann, Greg Roland, Jim Jordahl, Richard Harasick, Wayne Bamossy, Richard Coles, Lizanne Wheeler, Pat Brown, Kevin Burton, Rick Fornelli, Ileene Anderson, Melissa Riedel-Lehrke, Ron Tiller, and Jim Richards 2005. Managing salt to stabilize the Owens Playa with saltgrass. Presented at the Center for Water Resources, Salinity Conference, Sacramento California.

Rodgers, Jane and Ileene Anderson 2002. A Rare Mint (*Monardella robisonii*) in a Rock-Climbing Mecca. Joshua Tree National Park. April 2002. Pgs 25 + appendices.

Anderson, Ileene, Margot Griswold, Dana Kamada, and Adrian Wolf. 2001. Coyote Canyon Landfill: Native Vegetation Restoration Results in Habitat Creation for a Threatened Species. Poster given at Society for Conservation Biology. July 2001.

Hartman, Steve and Ileene Anderson 1999. California Deserts in Transition: Ecosystem Planning. Fremontia 27(2): 13-17.

Anderson, Ileene 1998. Status of Sensitive Plant Populations on Public Grazing Allotments within the California Desert Conservation Area. California Native Plant Society. August 1998 Pgs. 34.

BEFORE THE ENERGY RESOURCES CONSERVATION AND DEVELOPMENT COMMISSION OF THE STATE OF CALIFORNIA
1516 NINTH STREET, SACRAMENTO, CA 95814
1-800-822-6228 – WWW.ENERGY.CA.GOV

APPLICATION FOR CERTIFICATION FOR THE *PALEN SOLAR POWER PLANT PROJECT*

Docket No. 09-AFC-7

PROOF OF SERVICE
(Revised 8/27/10)

APPLICANT
Alice Harron
Senior Director of Project Development
*1111 Broadway, 5th Floor
Oakland, CA 94607
harron@solarmillenium.com

*Michael Cressner, Project Development & Permitting
Solar Millennium, LLC
1111 Broadway, 5th Floor
Oakland, CA 94709
cressner@solarmillennium.com

Arrie Bachrach
AECOM Project Manager
1220 Avenida Acaso
Camarillo, CA 93012
arrie.bachrach@aecom.com

Ram Ambatipudi
Chevron Energy Solutions
150 E. Colorado Blvd., Ste. 360
Pasadena, CA 91105
rambatipudi@chevron.com

Co-COUNSEL
Scott Galati, Esq.
Marie Mills
Galati/Blek, LLP
455 Capitol Mall, Suite 350
Sacramento, CA 95814
sgalati@gb-llp.com
mmills@gb-llp.com

Co-COUNSEL
Peter Weiner, Matthew Sanders
Paul, Hastings, Janofsky & Walker LLP
55 2nd Street, Suite 2400-3441
San Francisco, CA 94105
peterweiner@paulhastings.com
matthewsanders@paulhastings.com

INTERVENORS
California Unions for Reliable Energy (CURE)
c/o Tanya A. Gulesserian,
Marc D. Joseph
Jason W. Holder
Adams Broadwell Joseph & Cardozo
601 Gateway Boulevard,
Suite 1000
South San Francisco, CA 94080
tgulesserian@adamsbroadwell.com
jholder@adamsbroadwell.com*

Michael E. Boyd, President
Californians for Renewable Energy (CARE)
5439 Soquel Drive
Soquel, CA 95073-2659
michaelboyd@sbcglobal.net

Alfredo Figueroa
Californians for Renewable Energy (CARE)
424 North Carlton
Blythe, CA 92225
lacunadeaztlan@aol.com

Basin and Range Watch
Kevin Emmerich
Laura Cunningham
P.O. Box 153
Baker, CA 92309
atomictoadranch@netzero.net

Lisa T. Belenky, Senior Attorney
Center for Biological Diversity
351 California St., Suite 600
San Francisco, CA 94104
lbelenky@biologicaldiversity.org
Ileene Anderson
Public Lands Desert Director
Center for Biological Diversity
PMB 447, 8033 Sunset Boulevard
Los Angeles, CA 90046
ianderson@biologicaldiversity.org

INTERESTED AGENCIES
California ISO
e-recipient@caiso.com

Holly L. Roberts, Project Manager
Bureau of Land Management
Palm Springs-South Coast Field Office
1201 Bird Center Drive
Palm Springs, CA 92262
CAPSSolarBlythe@blm.gov

ENERGY COMMISSION
ROBERT WEISENMILLER
Commissioner and Presiding Member
rweisenm@energy.state.ca.us

KAREN DOUGLAS
Chairman and Associate Member
kldougla@energy.state.ca.us

Raoul Renaud
Hearing Officer
rrenaud@energy.state.ca.us

Alan Solomon
Siting Project Manager
asolomon@energy.state.ca.us

Lisa DeCarlo
Staff Counsel
ldecarlo@energy.state.ca.us

Jennifer Jennings
Public Adviser's Office
e-mail service preferred
publicadviser@energy.state.ca.us

*indicates change

DECLARATION OF SERVICE

I, Ileene Anderson, declare that on 10/6, 2010, I served and filed copies of the attached CBD opening testimony et al., dated 10/6, 2010. The original document, filed with the Docket Unit, is accompanied by a copy of the most recent Proof of Service list, located on the web page for this project at: [http://www.energy.ca.gov/sitingcases/solar_millennium_palen]

The documents have been sent to both the other parties in this proceeding (as shown on the Proof of Service list) and to the Commission's Docket Unit, in the following manner:

(Check all that Apply)

FOR SERVICE TO ALL OTHER PARTIES:

X sent electronically to all email addresses on the Proof of Service list;

____ by personal delivery;

____ by delivering on this date, for mailing with the United States Postal Service with first-class postage thereon fully prepaid, to the name and address of the person served, for mailing that same day in the ordinary course of business; that the envelope was sealed and placed for collection and mailing on that date to those addresses **NOT** marked "email preferred."

AND

FOR FILING WITH THE ENERGY COMMISSION:

X sending an original paper copy and one electronic copy, mailed and emailed respectively, to the address below (***preferred method***);

OR

____ depositing in the mail an original and 12 paper copies, as follows:

CALIFORNIA ENERGY COMMISSION
Attn: Docket No. 09-AFC-7
1516 Ninth Street, MS-4
Sacramento, CA 95814-5512
docket@energy.state.ca.us

I declare under penalty of perjury that the foregoing is true and correct, that I am employed in the county where this mailing occurred, and that I am over the age of 18 years and not a party to the proceeding.

*indicates change

Print

October 4, 2010

Germany Adds Nearly 1% of Electricity Supply with Solar in Eight Months

by Paul Gipe, Contributor

Seemingly determined to put an end to speculation that solar photovoltaics (PV) can't "scale" quickly enough to make a dent in electricity consumption, the German solar industry continues to break records.

According to the latest data from the *Bundesnetzagentur*, Germany's solar industry added another 1,000 MW during July and August. This brings the total for the eight-month period from January through August to 4,900 MW from nearly 175,000 solar installations.

Solar PV installations to date in 2010 are capable of generating slightly less than 5 TWh of electricity under German conditions.

Germany 2010 Solar PV Installations

	MW	Units
Jan	225	7,300
Feb	162	6,550
March	328	16,900
April	449	20,500
May	563	24,000
June	2,126	65,400
July	670	21,000
Aug	360	11,900
	4,883	173,550

Germany consumed 580 TWh of electricity in 2009.

Installations of solar PV during the first eight months of 2010 are capable of providing 0.86% or nearly 1% of the country's electricity. At the current pace of development, Germany will add about 6,000 MW of PV for all of 2010 or more than enough to provide 1% of electricity supply.

Germany currently meets approximately 1% of its supply with solar PV. With the 2010 additions, the country will meet 2% of its supply with solar PV.

Wind energy supplied 6.5% of Germany's electricity in 2009. Germany is expected to add another 4 TWh of generation from wind energy in 2010 or somewhat less than 1% of consumption.

Critics of solar energy have often charged that solar could not be scaled or installed quickly enough to have a significant effect on electricity supply. It is now clear that solar PV can indeed scale where the policies are designed to do so.

France

In other markets, France installed 200 MW of solar PV during the first six months of 2010, bringing total installations to 510 MW. There are 3,700 MW of solar PV projects and another 4,700 MW of wind projects awaiting interconnection.

North America

New Jersey's Clean Energy program estimates that, at the current pace, 125 MW of solar PV will be installed by year end, bringing total installations to nearly 250 MW.

The Canadian Solar Energy Industries Association (CanSIA) estimates that 100 to 200 MW of solar PV will be in installed in Ontario during 2010.

Industry analysts ClearSky Advisors estimates that total solar PV capacity in Ontario could reach nearly 700 MW by the end of 2011. Total PV installations could reach 3,000 MW by 2015.

In a related development, Italian solar manufacturer SilFab has announced that they will set up an assembly plant in a Toronto suburb and plan to produce 60 MW of solar PV in 2011.

On October 7, Enbridge, a Canadian operator of oil and natural gas pipelines, will dedicate the world's largest solar PV plant near Sarnia, Ontario. The 80 MW plant was begun by defunct California solar company Opti-Solar but was completed by Ohio's First Solar.

Ironically, North America's first commercial oil wells were drilled near Sarnia in 1858 and the region remains the center of the oil and chemical industry in Ontario.

In 2009, California added 200 MW of solar PV.

The US installed 435 MW of solar PV in 2009.

null

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California Public Utilities Commission
505 Van Ness Ave., San Francisco

FOR IMMEDIATE RELEASE **PRESS RELEASE**
Media Contact: Terrie Prosper, 415.703.1366, news@cpuc.ca.gov Docket #: A.08-03-015

CPUC APPROVES EDISON SOLAR ROOF PROGRAM

SAN FRANCISCO, June 18, 2009 - The California Public Utilities Commission (CPUC), in its ongoing commitment to innovative programs and policies to advance the delivery of renewable energy, today approved a solar photovoltaic program for Southern California Edison.

The program will result in the deployment of 500 megawatts (MW) of solar photovoltaic (PV) on existing commercial rooftops in Edison's service territory. Edison will own, install, operate, and maintain 250 MW of solar PV projects, which will primarily consist of one to two MW rooftop systems. The remaining 250 MW will be installed, owned, and operated by independent, non-utility solar providers selected through a competitive process.

Prior to today's decision, utility solar programs in the one to two MW range had limited participation in the California Solar Initiative or Renewables Portfolio Standard (RPS) program. Edison's program creates a new avenue for developing such smaller sized solar projects.

"This program represents a valuable complement to the existing renewable procurement efforts we have underway, given the significant permitting challenges large scale renewables face, both in terms of transmission and the generating facilities themselves," said CPUC President Michael R. Peevey. "It represents an important hedging strategy by allowing for the deployment of distributed resources that, while somewhat more expensive than the large scale renewable projects that are the primary focus of the RPS program, offer a much higher level of certainty in terms of when they will come online."

Added Commissioner John A. Bohn, author of the decision, "This decision is a major step forward in diversifying the mix of renewable resources in California and spurring the development of a new

market niche for large scale rooftop solar applications. Unlike other generation resources, these projects can get built quickly and without the need for expensive new transmission lines. And since they are built on existing structures, these projects are extremely benign from an environmental standpoint, with neither land use, water, or air emission impacts. By authorizing both utility-owned and private development of these projects we hope to get the best from both types of ownership structures, promoting competition as well as fostering the rapid development of this nascent market."

"This decision is good for California because it makes good use of all that sun and warehouse roofs in Southern California to produce clean energy right where we need it, both by Edison and independent generators," commented Commissioner Rachelle Chong. "I commend Edison for its foresight in bringing a focus on commercial solar PV projects that are 1-2 megawatts in size."

Commissioner Timothy Alan Simon said, "I support this decision because it strikes a balance between promoting utility-owned generation and competitive procurement for independent energy producers, as well as distributed generation and central station solar systems. Finally, it will bring much needed economic stimulus to the Inland Empire."

Because this is the first significant foray by a utility into ownership of renewable generation, the CPUC will carefully monitor the program's progress, examine ways in which the program can be improved, and fine tune the program when and where appropriate.

The energy generated from the project will be used to serve Edison's retail customers and the output from these facilities will be counted towards Edison's RPS goals. The output and capacity of the projects will not count towards the California Solar Initiative program goals.

The RPS program is one of the most ambitious renewable energy standards in the country. It requires investor-owned utilities to procure 20 percent of their electricity sales from renewable sources by 2010. Governor Schwarzenegger subsequently established an RPS target of 33 percent by 2020 for all retail sellers of electricity. The California Solar Initiative has a goal to install 3,000 MW of new customer solar projects by 2016, moving the state toward a cleaner energy future and helping lower the cost of solar systems for consumers.

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Date of Issuance – 5/26/09

PUBLIC UTILITIES COMMISSION OF THE STATE OF CALIFORNIA

ENERGY DIVISION **RESOLUTION E-4240**
May 21, 2009

REDACTED

R E S O L U T I O N

Resolution E-4240. Pacific Gas & Electric Company (PG&E) requests approval of a power purchase agreement (PPA) for generation from a new solar photovoltaic facility owned by El Dorado Energy, LLC. The project was bid into PG&E's 2008 Renewables Portfolio Standard solicitation and shortlisted by PG&E. This Resolution approves the PPA.

By Advice Letter 3386-E filed on December 22, 2008 and Supplemental Advice Letter 3386-E-A filed on January 9, 2009.

SUMMARY

PG&E's renewable contract complies with the Renewables Portfolio Standard (RPS) procurement guidelines and is approved.

PG&E filed Advice Letter (AL) 3386-E on December 22, 2008, requesting California Public Utilities Commission (Commission) review and approval of a renewable PPA with a new solar photovoltaic facility, El Dorado Energy, LLC (El Dorado Solar or Project). PG&E's request is granted because the PPA is consistent with Decision (D.) 08-02-008, which approved PG&E's 2008 RPS Procurement Plan. Deliveries from this contract are reasonably priced and fully recoverable in rates over the life of the contract, subject to Commission review of PG&E's administration of the contract. The energy acquired from the PPA will count towards PG&E's RPS requirements.

Generating Facility	Resource Type	Contract Term (Years)	Capacity (MW)	Expected Deliveries (GWh/yr)	Commercial Operation Date	Project Location
El Dorado Solar	Solar PV	20 years	10 MW	23 GWh/yr	January 1, 2009	Boulder City, Nevada

Confidential information about the contract should remain confidential

This resolution finds that certain material filed under seal pursuant to Public Utilities (Pub. Util.) Code Section 583, General Order (G.O.) 66-C, and D.06-06-066 should be kept confidential to ensure that market sensitive data does not influence the behavior of bidders in future RPS solicitations.

BACKGROUND

The RPS Program requires each utility to increase the amount of renewable energy in its portfolio

The California RPS Program was established by Senate Bill (SB) 1078, and has been subsequently modified by SB 107 and SB 1036. The RPS program is set forth in Public Utilities (Pub. Util.) Code Sections 399.11-399.20. An RPS is a market-based policy mechanism that requires a retail seller of electricity purchase a certain percentage of electricity generated by Eligible Renewable Energy Resources (ERR). Under the California RPS, each utility is required to increase its total procurement of ERRs by at least 1 percent of annual retail sales per year so that 20 percent of its retail sales are supplied by ERRs by 2010.[1]

In response to SB 1078 and SB 107, the Commission has issued a series of decisions that establish the regulatory and transactional parameters of the investor owned utility (IOU) renewables procurement program.[2]

- On June 19, 2003, the Commission issued its "Order Initiating Implementation of the Senate Bill 1078 Renewable Portfolio Standard Program," D.03-06-071.
- Instructions for utility evaluation of each offer to sell ERRs requested in an RPS solicitation were provided in D.04-07-029, as required by Pub. Util. Code §399.14(a)(2)(B). The bid evaluation methodology is known as 'least-cost, best-fit.'

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[1] On November 17, 2008, Governor Schwarzenegger signed Executive Order S-14-08, which established a 33 percent PRS target by 2020.

[2] RPS decisions are available on the Commission's RPS website: http://www.cpuc.ca.gov/PUC/energy/Renewables/decisions.htm

- The Commission adopted standard terms and conditions (STCs) for RPS power purchase agreements in D.04-06-014, as required by Pub. Util. Code §399.14(a)(2)(D). These STCs are compiled in D.08-04-009, as modified by D.08-08-028, and as a result there are now thirteen STCs of which four are non-modifiable.
- In D.06-05-039, the Commission required participation of an Independent Evaluator (IE) in the IOU's competitive RPS procurement process. The IE's role is to ensure that the IOU's RPS solicitation is undertaken in a fair and consistent manner. The IE also provides additional oversight during contract negotiations.
- D.06-10-050, as modified by D.07-03-046, outlined the RPS reporting and compliance methodologies and rules. In this decision, the Commission established methodologies to calculate a load serving entities' (LSE) initial baseline procurement amount, annual procurement target (APT) and incremental procurement amount (IPT).
- The Commission adopted its market price referent (MPR) methodology in D.04-06-015 for determining the utility's share of the RPS seller's bid price (the contract payments at or below the MPR), as defined in Pub. Util. Code §399.14(a)(2)(A) and 399.15(c). The Commission refined the MPR methodology in D.05-12-042 and D.08-10-026. Resolutions adopted MPR values for the 2005, 2006, 2007, and 2008 RPS solicitations.[3]
- In D.07-05-028, the Commission established a minimum quota for contracting with new facilities or executing long-term contracts for RPS-eligible generation. Specifically, in order for an LSE to count for RPS compliance, deliveries from contracts of less than 10 years' duration with RPS-eligible facilities that commenced commercial operation prior to January 1, 2005 must in each calendar year enter into contracts of at least 10 years' duration and/or short-term contracts with facilities that commenced commercial operation on or after January 1, 2005 for energy deliveries equivalent to at least 0.25% of that LSE's prior year's retail sales.

[3] MPR resolutions are available here:
http://www.cpuc.ca.gov/PUC/energy/Renewables/mpr

Pursuant to SB 1036, above-MPR costs may be recovered in rates

SB 1036[4] authorizes the Commission to provide above-MPR cost[5] recovery through electric retail rates for RPS contracts that are deemed reasonable. Above-MPR cost recovery has a 'cost limitation' equal to the amount of funds currently accrued in the California Energy Commission's New Renewable Resources Account, which had been established to collect supplemental energy payments (SEP funds), plus the portion of SEP funds that would have been collected through January 1, 2012. In addition, pursuant to SB 1036, Pub. Util. Code § 399.15(d)(2) provides that:

> "The above-market costs of a contract selected by an electrical corporation may be counted toward the cost limitation if all of the following conditions are satisfied:
>
> (A) The contract has been approved by the commission and was selected through a competitive solicitation pursuant to the requirements of subdivision(d) of Section 399.14.
>
> (B) The contract covers a duration of no less than 10 years.
>
> (C) The contracted project is a new or repowered facility commencing commercial operations on or after January 1, 2005.
>
> (D) No purchases of renewable energy credits may be eligible for consideration as an above-market cost.
>
> (E) The above-market costs of a contract do not include any indirect expenses including imbalance energy charges, sale of excess energy, decreased generation from existing resources, or transmission upgrades."

PG&E requests Commission approval of a new renewable energy contract

On December 22, 2008, PG&E filed AL 3386-E requesting Commission approval of a renewable procurement contract with El Dorado Energy, LLC. The PPA results from PG&E's 2008 RPS Solicitation. The Commission's approval of the

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[4] Chapter 685, Statutes of 2007 (SB 1036)

[5] "Above-market costs" refers to the portion of the contract price that is greater than the appropriate market price referent (MPR).

PPA will authorize PG&E to fully recover in rates, payments made pursuant to the PPA.

PG&E requests that the Commission issue a resolution containing the findings necessary for "CPUC Approval" as defined in Appendix A of D.04-06-014. In addition, PG&E requests that the Commission issue a resolution that does the following:

1. Approves the PPA in its entirety, including payments to be made by PG&E pursuant to the PPA, subject to the Commission's review of PG&E's administration of the PPA.
2. Finds that any procurement pursuant to the PPA is procurement from an eligible renewable energy resource for purposes of determining PG&E's compliance with any obligation that it may have to procure eligible renewable energy resources pursuant to the California Renewables Portfolio Standard (Public Utilities Code Section 399.11 et seq.) ("RPS"), Decision ("D.") 03-06-071 and D.06-10-050, or other applicable law.
3. Finds that all procurement and administrative costs, as provided by Public Utilities Code section 399.14(g), associated with the PPA shall be recovered in rates.
4. Adopts the following finding of fact and conclusion of law in support of CPUC Approval:
    a. The PPA is consistent with PG&E's approved 2008 RPS procurement plan.
    b. The terms of the PPA, including the price of delivered energy, are reasonable.
5. Adopts the following finding of fact and conclusion of law in support of cost recovery for the PPA:
    a. The utility's cost of procurement under the PPA shall be recovered through PG&E's Energy Resource Recovery Account.
    b. Any stranded costs that may arise from the PPA are subject to the provisions of D.04-12-048 that authorize recovery of stranded renewables procurement costs over the life of the contract. The implementation of the D.04-12-048 stranded cost recovery mechanism is addressed in D.08-09-012.

6. Adopts the following findings with respect to resource compliance with the Emissions Performance Standard ("EPS") adopted in R.06-04-009:

    a. The PPA is not a covered procurement subject to the EPS because the generating facility has a forecast annualized capacity factor of less than 60% and therefore is not baseload generation under paragraphs 1(a)(ii) and 3(2)(a) of the Adopted Interim EPS Rules.

PG&E's Procurement Review Group participated in review of the PPA

In D.02-08-071, the Commission required each utility to establish a "Procurement Review Group" (PRG) whose members, subject to an appropriate non-disclosure agreement, would have the right to consult with the utilities and review the details of each utility's:

1. Overall interim procurement strategy;
2. Proposed procurement processes including, but not limited to, requests for offers (RFOs); and
3. Proposed procurement contracts before any of the contracts are submitted to the Commission for expedited review.

The PRG for PG&E consists of: California Department of Water Resources (DWR), the Commission's Energy Division, Union of Concerned Scientists (UCS), Division of Ratepayer Advocates (DRA), Coalition of California Utility Employees (CUE) and The Utility Reform Network (TURN).

PG&E informed its PRG of the El Dorado Solar negotiations on August 6, 2008 and October 17, 2008.[6] These presentations included a general overview of the negotiated terms and conditions, rationale for selection, and assessment of the PPA's price. PG&E stated that none of the PRG members objected to PG&E's execution of the PPA.

Energy Division reviewed the transaction independently of the PRG and allowed for a full protest period before concluding its analysis.

---

[6] PG&E inadvertently cited the incorrect PRG dates in AL 3386-E.

NOTICE

Notice of AL 3386-E and Supplemental AL 3386-E-A was made by publication in the Commission's Daily Calendar. PG&E states that a copy of the Advice Letter was mailed and distributed in accordance with Section IV of General Order 96-B.

PROTESTS

On January 12, 2009, DRA filed a timely protest with the Commission. DRA's protest was submitted as confidential and was fully redacted. PG&E filed a timely confidential response with the Commission on January 20, 2009.

DISCUSSION

The following table summarizes the substantive features of the PPA. See Confidential Appendix B for a detailed discussion of contract terms and conditions.

Generating Facility	Resource Type	Contract Term (Years)	Capacity (MW)	Annual Deliveries (GWh)	Commercial Operation Date	Project Location
El Dorado Solar	Solar PV	20 years	10 MW	23 GWh	January 1, 2009	Boulder City, Nevada

The El Dorado Solar project (Project) was completed and deemed operational at the end of 2008. El Dorado Solar utilizes proven technology, specifically, fixed-tilt, thin-film photovoltaic panels, to produce RPS-eligible energy.

PG&E began accepting deliveries from the Project on January 1, 2009. Pursuant to the PPA, PG&E pays El Dorado Solar a daily market index price for all generation prior to receiving CPUC Approval. If CPUC Approval is attained, PG&E will then pay El Dorado Solar the PPA price for each megawatt hour (MWh) of generation and will pay a onetime true-up settlement payment.[7]

[7] The true-up settlement payment will equal the difference between the PPA price and the daily market index price paid prior to CPUC Approval.

PG&E did not receive Commission approval of its PPA with El Dorado Solar prior to taking deliveries under the PPA. In general, CPUC approval is required for generation under a PPA to be used for RPS compliance. In this instance, because the PPA conforms to the Commission's procurement guidelines, and the fact that PG&E was in the unique position of executing a PPA with a new facility on the eve of its achieving commercial operation, there is no harm to ratepayers from PG&E's failure to submit the contract for approval in a timely manner.

Energy Division has reviewed the proposed PPA pursuant to Commission decisions

Specifically, Energy Division evaluated the PPA for the following criteria:

- Consistency with PG&E's 2008 RPS procurement plan
- Consistency with RPS Standard Terms and Conditions (STC)
- Reasonableness of the levelized all-in price
- Project viability assessment
- Consistency with Emissions Performance Standard
- SB 1036 guidelines

PPA is consistent with PG&E's Commission adopted 2008 RPS Plan

California's RPS statute requires that the Commission review the results of a renewable energy resource solicitation submitted for approval by a utility.[8] PG&E's 2008 RPS procurement plan (Plan) was approved by D.08-02-008 on February 14, 2008. Pursuant to statute, PG&E's Plan includes an assessment of supply and demand to determine the optimal mix of renewable generation resources, consideration of flexible compliance mechanisms established by the Commission, and a bid solicitation protocol setting forth the need for renewable generation of various operational characteristics.[9]

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[8] Pub. Util. Code, Section §399.14

[9] Pub. Util. Code, Section §399.14(a)(3)

PPA is consistent with identified resource needs

The stated goal of PG&E's 2008 RPS Solicitation Plan was to procure 1-2 percent of PG&E's retail sales volume or between 750 and 1,500 GWh per year to achieve 20 percent renewables by 2010. This PPA is consistent with PG&E's 2008 Plan because, if approved, generation from the 10 MW facility will contribute to PG&E's 2010 RPS requirement.

PPA selection is consistent with RPS Solicitation Protocol

The independent evaluator[10] (IE) has verified that the PPA is consistent with PG&E's objectives set forth in its 2008 RPS Plan. The IE's project specific report included a discussion of how PG&E added El Dorado Solar to its 2008 RPS shortlist after the final shortlist had been submitted to the Commission. The IE appropriately highlights this event because it has an appearance that one project was treated differently than other bidders. In fact, El Dorado Energy, LLC clarified the details of its proposed project, which resulted in a decision by PG&E to add El Dorado Solar to its shortlist. The IE concludes that no other individual bid, solicitation participant, or project appears to have been disadvantaged by PG&E's actions. Finally, the IE supports PG&E's decision to execute discussed herein and concurs with PG&E that the PPA merits CPUC Approval.[11]

We agree with PG&E's IE. Rather than add El Dorado Solar to its shortlist late in the Solicitation schedule, PG&E instead could have pursued the Project as a bilateral. Doing so, would have been consistent with PG&E's Solicitation Protocol, but would not necessarily have been in the best interest of ratepayers. The benefits of having El Dorado Solar added to PG&E's shortlist are that the IE then participates in the evaluation and negotiations with the counterparties. The Commission requires the use of an IE, in part, because of the benefits third party oversight provides to the procurement process. We believe that adhering to the Solicitation Protocol is singularly important so that one bidder is not advantaged

---

[10] PG&E employed Arroyo Seco Consulting as independent evaluator for its 2008 RPS Solicitation.

[11] First Advice Letter Report of the Independent Evaluator on the Bid Evaluation and Selection Process. (AL 3386-E, Appendix I, page 53.)
http://www.pge.com/nots/rates/tariffs/tm2/pdf/ELEC_3386-E.pdf

over another. However, on balance, we accept PG&E's departure in this instance because the IE determined that no other bidder was disadvantaged and because shortlisting the Project enabled the IE to continue its oversight of the parties negotiations.

PPA selection consistent with LCBF requirements

The LCBF decision directs the utilities to use certain criteria in their bid ranking.[12] The decision offers guidance regarding the process by which the utility ranks bids in order to select or "shortlist" the bids with which it will commence negotiations. PG&E's solicitation protocol included an explanation of its LCBF methodology. The IE oversaw the bid evaluation process and concluded in its report that the LCBF evaluation methodology was generally employed consistently and the process was conducted fairly. El Dorado Solar's superior project viability elevated its LCBF ranking.

Qualitative Factors

PG&E considered qualitative factors as required by D.04-07-029 and D.08-02-008 when evaluating the PPA. Approval of the PPA will add to the diversity of technologies in PG&E's renewables portfolio. El Dorado Solar represents the first operational solar photovoltaic project in PG&E's portfolio.

Consistency with Adopted Standard Terms and Conditions

The proposed PPA conforms to the Commission's decisions requiring STCs for RPS contracts.

"May Not be Modified" Terms

The PPA does not deviate from the non-modifiable terms and conditions.

"May be Modified" Terms

During the course of negotiations, the parties identified a need to modify some of the modifiable standard terms in order to reach agreement. The changes were based upon mutual agreement reached during negotiations.

[12] D.04-07-029

PPA price is reasonable and recoverable in rates

The levelized price is greater than the 2008 MPR,[13] but the PPA price is reasonable when compared to other bids PG&E received through its 2008 RPS solicitation. Specifically, El Dorado Solar was competitive relative to other solar PV bids and PG&E believed at the time of contract execution that the Project's viability was high. Confidential Appendix B includes a detailed discussion of the PPA's pricing terms.

Project is Eligible for Above Market Funds

El Dorado Solar meets the eligibility criteria for Above Market Funds (AMFs) established in SB 1036 and provided in the background section of this resolution. This Project is eligible for AMFs.

Above Market Funds May Not be Available

PG&E may not have sufficient AMFs to meet the needs of this Project.[14] The RPS statute provides that if PG&E's AMF fund is exhausted, PG&E may enter into contracts to procure RPS eligible energy, that exceed the MPR, and that this Commission may approve the costs of the contract in rates. Specifically, while the Commission must allow an IOU to limit its procurement to the quantity of eligible renewable energy resources that can be procured at or below the MPR once its AMF funds are depleted, § 399.15 (d)(4) states:

> Nothing in this section prevents an electrical corporation from voluntarily proposing to procure eligible renewable energy resources at above-market prices that are not counted toward the cost limitation. Any voluntary procurement involving above-market costs shall be subject to commission approval prior to the expense being recovered in rates.

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[13] See Resolution E-4214

[14] On March 12, 2009, the Commission adopted Resolution E-4199, which implements SB 1036. Pursuant to Resolution E-4199, on April 16, 2009, the IOUs submitted AMF Calculators to the Director of Energy Division that reveals each utility's AMF balance. The Director of Energy Division will notify the IOUs and relevant service lists about what each IOU's AMF balance is after Energy Division staff reviews the materials submitted.

PG&E has not yet hit its 20 percent RPS target, but has nonetheless likely contracted for enough above-MPR RPS-eligible energy to have met its cost limitation. This implies either that the utility has been signing unnecessarily expensive contracts, or that the above-market funds set aside by the legislature in 2002 are insufficient for meeting the state's RPS goals in the manner envisioned by statute.

The Commission believes the latter to be true. The prices bid into RPS solicitations have risen consistently since 2002, and although the MPR has risen as well, the utilities are having difficulty filling their RPS procurement needs with viable, "least cost, best fit" projects, without exceeding their respective AMF allocations. As described above, the Independent Evaluator for PG&E's 2008 RPS solicitation concluded that PG&E conducted its solicitation and subsequent contract negotiations in a fair and reasonable manner. The El Dorado Solar PPA that resulted from that competitive solicitation represents a valuable balance of viability and cost reasonableness. Consequently, the Commission finds it to be reasonably consistent with PG&E's approved 2008 RPS Plan, and that approving the PPA is in the interest of PG&E's ratepayers.

Transmission and delivery

No transmission upgrades are necessary for PG&E to accept deliveries from the Project. El Dorado Solar is located in NV Energy's service territory; however, there is a contiguous transmission path from the facility to California Independent System Operator's control area, via Sempra's Eldorado-Merchant 230 kv transmission line. The seller will schedule and deliver generation from the Project to PG&E at the 230 kv El Dorado Substation, which is located in the CAISO control area.

Contribution to minimum quota requirement for long-term/new facility contracts

As a new facility, delivering pursuant to a long-term PPA, deliveries from El Dorado Solar will contribute to PG&E's minimum quota requirement under D.07-05-028, described above.

PG&E began procuring energy under the PPA prior to obtaining Commission approval of the PPA

PG&E filed the PPA with the Commission on December 22, 2008, and began procuring energy under the PPA on January 1, 2009, prior to obtaining

Commission approval of the PPA. As a general rule, this Commission requires that a utility seek approval of long-term contracts prospectively. PG&E accordingly placed itself at some risk by incurring costs under the PPA, as the Commission could potentially deny or condition approval of the PPA. Under the specific circumstances of this case, the Commission concludes that advice letter should be approved, despite PG&E's "jumping the gun."

The IOUs are granted significant flexibility to enter into a variety of contracts[15] with RPS-eligible generators, subject to RPS procurement rules set out in statute and Commission decisions. Once filed for approval, Energy Division staff evaluates whether the IOU adhered to its protocols set forth in its RPS procurement plan, consistency with Commission decisions, and whether the PPA itself is reasonable and in the best interest of ratepayers.

In this instance, PG&E discussed the project with its PRG, the PPA complies with Commission decisions, and we have determined that the price is reasonable. Furthermore, PG&E filed the PPA by advice letter permitting a full comment period, and no party protested that the PPA should not be approved. On balance, there is no harm to ratepayers from PG&E's failure to submit the PPA for approval in a timely manner. Accordingly, the Commission finds, based on the specific facts in this case, that PG&E's failure to submit this advice letter in a timely manner should not preclude or alter our approval of the PPA. Our approval of this PPA is not precedential, and does not constitute any change in standard Commission procedures or practices.

DRA filed a confidential protest to PG&E's advice letter

On January 12, 2009, DRA filed a confidential protest to AL 3386-E with the Commission. Of course, we are limited in how we can respond to DRA's confidential protest. We note that DRA did not oppose Commission approval of PG&E's PPA with El Dorado Solar, but rather, DRA's protest related to the process by which the PPA was selected. For the reasons discussed above, we find that that PG&E's bid evaluation and selection process was conducted fairly, and accordingly we reject DRA's protest. (See Confidential Appendix A)

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[15] For example; an IOU may seek approval for bilateral contracts, contracts with existing facilities, and short-term contracts (less than 10 years).

COMMENTS

Public Utilities Code section 311(g)(1) provides that this resolution must be served on all parties and subject to at least 30 days public review and comment prior to a vote of the Commission. Section 311(g)(2) provides that this 30-day period may be reduced or waived upon the stipulation of all parties in the proceeding.

The 30-day comment period for the draft of this resolution was neither waived nor reduced. Accordingly, this draft resolution was mailed to parties for comments on April 9, 2009.

No comments were filed.

FINDINGS

1. PG&E filed Advice Letter (AL) 3386-E on December 22, 2008 requesting Commission review and approval of a renewable energy resource power purchase agreement (PPA) with El Dorado Energy, LLC.
2. PG&E filed Supplemental Advice Letter 3386-E-A on January 7, 2009, to correct PG&E's above-MPR funds calculation presented in AL 3386-E.
3. The RPS Program requires each utility, including PG&E, to increase the amount of renewable energy in its portfolio to 20 percent by 2010, increasing by a minimum of one percent per year.
4. November 17, 2008, Governor Schwarzenegger issued Executive Order S-14-08, which sets a target for energy retailers to deliver 33 percent of electrical energy from renewable resources by 2020.
5. The PPA is consistent with PG&E's approved 2008 RPS Procurement Plan, which was approved by D.08-02-008.
6. D.04-06-014 and D.07-11-025 set forth standard terms and conditions to be incorporated into each RPS PPA. Those terms were compiled and published by D.08-04-009.
7. The PPA includes the Commission adopted RPS Standard Terms and Conditions deemed "non-modifiable".
8. A confidential protest to AL 3386-E was filed by DRA on January 12, 2009, and PG&E responded to the protest, confidentially, on January 20, 2009.

9. Any stranded costs that may arise from the PPA are subject to the provisions of D.08-09-012 that authorize recovery of stranded renewables procurement costs over the life of the contract.
10. D.06-05-039 requires participation of an independent evaluator in RPS solicitations.
11. The independent evaluator employed for PG&E's 2008 RPS solicitation concluded in its report that PG&E's bid evaluation and selection process was conducted fairly.
12. The Commission supports the IE's finding that PG&E's bid evaluation and selection process was conducted fairly.
13. PG&E began to take delivery under the PPA prior to receiving CPUC approval for AL 3386-E.
14. PG&E should have obtained CPUC approval prior to taking delivery under the PPA.
15. PG&E's failure to submit this advice letter in a timely manner did not cause any ratepayer harm.
16. DRA's confidential protest is rejected for the reasons stated above.
17. The Commission requires each utility to establish a Procurement Review Group (PRG) to review the utilities' interim procurement needs and strategy, proposed procurement process, and selected contracts.
18. Procurement pursuant to the PPA is procurement from an eligible renewable energy resource for purposes of determining PG&E's compliance with any obligation that it may have to procure eligible renewable energy resources pursuant to the California Renewables Portfolio Standard (Public Utilities Code Section 399.11 et seq.), D.03-06-071 and D.06-10-050, or other applicable law.
19. The payments made under this PPA between PG&E and El Dorado Energy, LLC are reasonable and in the public interest; accordingly, the payments to be made by PG&E are fully recoverable in rates over the life of the project, subject to Commission review of PG&E's administration of the PPA.
20. Certain material filed under seal pursuant to Public Utilities (Pub. Util.) Code Section 583 and General Order (G.O.) 66-C, and considered for possible disclosure, should not be disclosed. Accordingly, the confidential appendices,

marked "**[REDACTED]**" in the redacted copy, should not be made public upon Commission approval of this resolution.

21. The PPA is reasonable and should be approved.
22. AL 3386-E, as supplemented by AL 3386-E-A, should be approved effective today.

THEREFORE IT IS ORDERED:

1. AL 3386-E, as supplemented by AL 3386-E-A, is approved.

This Resolution is effective today.

I certify that the foregoing resolution was duly introduced, passed and adopted at a conference of the Public Utilities Commission of the State of California held on May 21, 2009; the following Commissioners voting favorably thereon:

_____
PAUL CLANON
Executive Director

MICHAEL R. PEEVEY
PRESIDENT
DIAN M. GRUENEICH
JOHN A. BOHN
RACHELLE B. CHONG
TIMOTHY ALAN SIMON
Commissioners

Confidential Appendix A

Disposition of Confidential Protest from the Division of Ratepayer Advocates

[REDACTED]

Confidential Appendix B

Contract Analysis

[REDACTED]

Solar | Ucilia Wang | **April 22, 2009**

0 Comments

Sempra Wants 300MW Plus of Solar in Arizona

The power plant developer is looking at different solar technologies for a project in Arizona. Panels are cheaper than thermal, says the CEO.

Sempra Generation aims to build at least 300 megawatts of solar power projects on land it owns in Arizona, and it plans to start construction next year, said CEO Michael Allman on Wednesday.

The power producer plans to replicate what it has done in Nevada, where it has built a 10-megawatt solar power plant next to its existing 480-megawatt natural-gas power plant. San Diego, Calif.-based Sempra is expanding the solar power project in Nevada by adding another 48 megawatts (see **First Solar to Build 48MW Power Plant for Sempra**).

Speaking at the Dow Jones Alternative Energy Innovation conference near San Francisco, Allman said the company plans to build more than 300 megawatts worth of solar projects on 4,000-plus acres it owns near Phoenix, Ariz., where it also already runs **a 1.25-gigawatt natural gas power plant**. Building the solar power farm next to the conventional power plant helps to reduce costs by being close to existing transmission lines.

The Arizona solar plan, called Mesquite Solar, would be built over many years. Allman declined to say how much money the company plans to invest in the plan, or the size of the first project. Sempra develops, owns and operates power plants and sells electricity to utilities in Nevada, California and Arizona.

Arizona is becoming more aggressive about solar technologies. It offers a $3 per watt credit, nearly twice as high as California's. Baseline power in the state, however, is comparatively cheap so some of the advantage is eroded. Nonetheless, some power providers want to produce power in Arizona to sell to California.

Sempra has leaped into the solar power development business with a vengeance. The 10-megawatt project in Nevada was the first in solar for the company, which started selling electricity from the plant to utility Pacific Gas and Electric Co. in Northern California in January this year (see **PG&E to Get Solar Power for the First Time**).

Sempra is part of **Sempra Energy** (NYSE: SRE), which also owns San Diego Gas & Electric, a utility in Southern California. Allman said his company has the financial muscle to develop solar energy, unlike other companies that have had to delay or ditch projects altogether.

"There is a tempering of optimism in the business," Allman said. "There was a time when people had stars in their eyes."

Sempra would open to buy or co-develop projects from developers who can't complete them on their own, Allman said. The company didn't bid for the gigawatts worth of unfinished projects from OptiSolar, however. OptiSolar ended up selling those projects, located mostly in western United States, to First Solar for about $400 million earlier this year (see **First Solar Buys OptiSolar's Power Projects**).

Sempra is fond of First Solar, which has been making solar panels for years and jumped into the power plant building business in earnest over the past year. First Solar built the 10-megawatt project in Nevada, and snagged the deal to add 48 megawatts next to it.

The company picked First Solar because First Solar could supply panels cheaper than others, Allman said. Tempe, Ariz.-based First Solar makes cadmium-telluride panels and is rapidly expanding its factories in the United States and Malaysia to reduce costs.

"The electricity we are getting out of the 10-megawatt is the lowest cost solar energy ever generated from anywhere in the world. I've had that statement out there for a while, and no one has challenged me," Allman said, who declined to disclose the cost.

Given that delivering cheap solar electricity is key to winning utility contracts, Sempra could well pick First Solar again for its Mesquite Solar project. Allman said no decision has been made, and he would consider using other types of solar panels, including the more expensive crystalline silicon variety.

Crystalline silicon panels in general cost more to make because silicon is expensive, but they also can convert sunlight into electricity at higher rates than competing photovoltaic technologies. But silicon prices are falling, and that could make crystalline silicon panels a

more attractive option, he added.

Sempra has also evaluated solar thermal power technologies, which use a field of mirrors to concentrate the sunlight to produce heat for electricity generation. The company has found that using solar panels is the cheaper option, Allman said. He noted that some of the solar-thermal power technologies, such as the use of a central tower for harvesting the heat and generating steam, have yet to be proven commercially.

Building solar power plants require lots of land. The general rule is to set aside 8 acres for building every megawatt of generation capacity, Allman said. The company bought those 4,000-plus acres in Arizona for the underground water rights many years ago, however, because its natural gas power plant uses water-cooling, Allman said.

News Release

First Solar Sells California Solar Power Project to NRG

21 Megawatt Blythe Project is California's Largest Photovoltaic Facility

TEMPE, Ariz., Nov 23, 2009 (BUSINESS WIRE) -- First Solar, Inc. (Nasdaq:FSLR), today announced the sale of the 21 megawatt (MW) AC solar energy project it has developed and constructed in Blythe, Calif., to NRG Energy, Inc.

Located in Riverside County about 200 miles east of Los Angeles, the Blythe project is California's first and largest utility-scale photovoltaic (PV) solar generation facility, and among the largest in North America. Construction began in September and is expected to be completed by year-end. Electricity from the plant will be sold to Southern California Edison under a 20-year power purchase agreement.

"First Solar is very pleased that the first of our utility-scale solar projects in California will be coming on line with a leading power producer like NRG," said Bruce Sohn, president of First Solar. "This clean, affordable, and sustainable energy will help California meet the goals of its Renewable Portfolio Standard."

Using First Solar's industry-leading thin film PV panels that convert sunlight directly into electricity with no water consumption during operation, the project will generate over 45,000 megawatt-hours of electricity per year. The solar generation displaces over 12,000 tons of carbon dioxide emissions per year--the equivalent of taking 2,200 cars off the road. The construction of this project created 175 green jobs.

First Solar will provide operations and maintenance services at Blythe under a long-term contract with NRG. Financial terms of the agreement were not disclosed.

First Solar is developing 1,300 megawatts of PV solar projects under contracts with utilities in California and the Southwest.

About First Solar

First Solar manufactures solar modules with an advanced semiconductor technology and provides comprehensive photovoltaic (PV) system solutions. By continually driving down manufacturing costs, First Solar is delivering an economically viable alternative to fossil-fuel generation today. From raw material sourcing through end-of-life collection and recycling, First Solar is focused on creating cost-effective, renewable energy solutions that protect and enhance the environment. For more information about First Solar, please visit www.firstsolar.com.

For First Solar Investors

This release contains forward-looking statements which are made pursuant to the safe harbor provisions of Section 21E of the Securities Exchange Act of 1934. The forward-looking statements in this release do not constitute guarantees of future performance. Those statements involve a number of factors that could cause actual results to differ materially, including risks associated with the company's business involving the company's products, their development and distribution, economic and competitive factors and the company's key strategic relationships and other risks detailed in the company's filings with the Securities and Exchange Commission. First Solar assumes no obligation to update any forward-looking information contained in this press release or with respect to the announcements described herein.

SOURCE: First Solar, Inc.

First Solar, Inc.
Media Contact:
Alan Bernheimer, 602-414-9361
media@firstsolar.com
Investor Contact:
Larry Polizzotto, 602-414-9315
investor@firstsolar.com

BEFORE THE PUBLIC UTILITIES COMMISSION OF THE

STATE OF CALIFORNIA

Application of Southern California Edison Company (U 338-E) for Authority to Implement and Recover in Rates the Cost of its Proposed Solar Photovoltaic (PV) Program.	)))))	A_____

APPLICATION OF SOUTHERN CALIFORNIA EDISON COMPANY (U 338-E) FOR AUTHORITY TO IMPLEMENT AND RECOVER IN RATES THE COST OF ITS PROPOSED SOLAR PHOTOVOLTAIC (PV) PROGRAM

DOUGLAS K. PORTER
CAROL A. SCHMID-FRAZEE
ANNETTE GILLIAM

Attorneys for
SOUTHERN CALIFORNIA EDISON COMPANY

2244 Walnut Grove Avenue
Post Office Box 800
Rosemead, California 91770
Telephone: (626) 302-1337
Facsimile: (626) 302-1935
E-mail:carol.schmidfrazee@sce.com

Dated: March 27, 2008

APPLICATION

TABLE OF CONTENTS

Section	Title	Page
I.	SUMMARY OF REQUEST	1
II.	SUMMARY OF REASONS FOR REQUEST	3
III.	NEED FOR PROJECT AND PROJECT DESCRIPTION	5
A.	Need for Project	5
1.	Solar PV Program Complements The Existing California Solar Initiative (CSI) And Renewable Portfolio Standard Programs	5
2.	SCE Can Best Develop Solar PV Program	8
3.	The Solar PV Program Could Drive Costs Down And Increase Efficiencies	9
B.	Project Description	10
1.	The Solar PV Program Will Provide Up To 250 MW Of Renewable Generation Over The Next Five Years	10
2.	Use of Rooftop Space for Facilities	11
3.	Program Costs	12
a)	Capital	12
b)	O&M Costs	13
IV.	PROPOSAL FOR COST RECOVERY	14
A.	The Commission Should Adopt SCE's Proposed Solar PV Program Balancing Account (SPVPBA) For Rate Recovery of Solar PV Program Costs	14
B.	The Commission Should Adopt SCE's Proposed Reasonableness Standard For These Clean, Renewable Generation Resources	15
V.	THIS APPLICATION FOR RECOVERY OF THE SOLAR PV PROGRAM'S COST IS EXEMPT FROM CEQA REVIEW	17
VI.	STATUTORY AND PROCEDURAL REQUIREMENTS	19
A.	Statutory and Procedural Authority	19

APPLICATION

TABLE OF CONTENTS

Section	Title	Page
B.	Rule 2.1	20
1.	Proposed Categorization	20
2.	Need for Hearings and Proposed Schedule for Resolution of Issues	20
3.	Issues to be Considered	21
4.	Legal Name and Correspondence	21
C.	Articles of Incorporation – Rule 2.2	22
D.	Authority to Increase Rates – Rule 3.2	22
1.	Balance Sheet and Income Statement – Rule 3.2(a)(1)	22
2.	Present and Proposed Rates – Rule 3.2(a)(2) and (a)(3)	23
3.	Description of SCE's Service Territory and Utility System – Rule 3.2(a)(4)_	23
4.	Summary of Earnings – Rule 3.2(a)(5)	23
5.	Depreciation – Rule 3.2(a)(7)	23
6.	Capital Stock and Proxy Statement – Rule 3.2(a)(8)	23
7.	Statement Pursuant to Rule 3.2(a)(10)	23
8.	Service of Notice – Rule 3.2(b), (c) and (d)	24
E.	Service List	24
VII.	CONCLUSION	24

Appendix A
Southern California Edison Company's Balance Sheet and Income Statement

Appendix B
Southern California Edison Company's 2008 Summary of Earnings

Appendix C
List of Cities and Counties

APPLICATION

TABLE OF CONTENTS

Section	Title	Page
Appendix D		
	Background Information on CSI	

LIST OF TABLES

Table	Page
Table III-1 Solar PV Program Estimated Base Case Capital Costs (2008$ 000)	13
Table IV-2 Reasonableness Review Threshold For Solar PV Program Direct Capital Costs (2008$)	16

BEFORE THE PUBLIC UTILITIES COMMISSION OF THE

STATE OF CALIFORNIA

Application of Southern California Edison Company (U 338-E) for Authority to Implement and Recover in Rates the Cost of its Proposed Solar Photovoltaic (PV) Program.	)))))	A.08-03-_____

APPLICATION OF SOUTHERN CALIFORNIA EDISON COMPANY (U 338-E) FOR AUTHORITY TO IMPLEMENT AND RECOVER IN RATES THE COST OF ITS PROPOSED SOLAR PHOTOVOLTAIC (PV) PROGRAM

I.

SUMMARY OF REQUEST

Pursuant to Rule 3.2 of the California Public Utilities Commission (Commission or CPUC) Rules of Practice and Procedure, Southern California Edison Company (SCE) hereby submits this application requesting the Commission to:

(1) Find it reasonable for SCE to implement a Solar Photovoltaic (PV) Program that would consist of up to 250 megawatts (MW)[1] of utility-owned solar PV generating facilities of approximately 1 to 2 MW[2] each over the next five years;

(2) Establish ratemaking for SCE's Solar PV Program, specifically including:

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[1] Unless otherwise specified, any reference to energy output in this filing follows the common convention within the PV industry, which is to refer to output as PV panel direct current (dc) output. Additionally, SCE proposes using installed dc output in reasonableness reviews because installation occurs in dc panels. The conversion factor of 0.90 will be used to convert from MW dc to MW alternating current (ac) based on sample calculations using the California Energy Commission's ac MW to conversion (i.e., multiply MW dc by 0.90 to obtain MW CEC-ac Rating).

[2] SCE envisions the individual Solar PV Program installations to be in the 1 to 2 MW range. As the program proceeds, however, some installations may be larger or smaller than this range due to roof size or circuit loading considerations.

a) Provision for each solar PV facility to receive rate-base recovery upon its completion, subject to adjustment following reasonableness review if direct capital expenditures exceed certain $/Watt (W) thresholds each year on average;[3] and

b) Provision for recovery of reasonable Operation and Maintenance (O&M) expenses.

(3) Establish an annual estimate of average reasonable capital costs, based on a $/W threshold, below which no reasonableness review is required;

(4) Require SCE to refer the owner/developer of new structures seeking to participate in the Solar PV Program to SCE's Energy Efficiency group for assistance in identifying potential energy efficiency measures that could be incorporated into new structures;

(5) Find that SCE's proposed Solar PV Program will not require California Environmental Quality Act (CEQA)[4] review at this Commission;

(6) Establish a new balancing account for recovery of all Solar PV Program costs subject to annual reasonableness review of O&M expenses and reasonableness review of capital expenditures only if capital expenditures exceed a certain $/W reasonableness threshold on average in a given year; and

(7) Establish, through a resolution approving SCE's concurrently filed Advice Letter, a new memorandum account. This will provide a mechanism for recovery of 100% of reasonable start-up costs for the Solar PV Program. If the Commission disapproves the remainder of SCE's application, SCE may request recovery of actually incurred capital expenditures and O&M costs. SCE estimates capital expenditures of $25 million in 2008. If the Commission does not act on this

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[3] See Table IV-2, infra, for proposed reasonableness thresholds in $/W.

[4] Cal. Public Resources Code §§21000, et seq.

application in 2008, SCE will continue to record the Solar PV Program costs in the memorandum account in 2009.

SCE proposes immediate start-up of the Solar PV Program. If the program is successful, SCE may seek additional authority to expand the program to 500 MW. An expansion to 500 MW would seek to maintain the momentum of that success. So, there is no hiatus in installing new systems. SCE requests the Commission grant all of its requests and authorize recovery of all costs of the Solar PV Program, including those in the memorandum account, through SCE's proposed Solar PV Program balancing account ratemaking mechanism. SCE requests such approval by year-end 2008.

II.

SUMMARY OF REASONS FOR REQUEST

SCE makes these requests, because:

- California is endowed with abundant solar resources. In recent years, the State has taken bold steps to develop this resource, but more can be done.
- State policies support increased use of solar PV resources primarily through implementation of the California Solar Initiative (CSI). Proceeding with 250 MW of utility-owned solar PV generating facilities will support policies established in the CSI to increase generation of solar PV energy. The output of the program will also count toward meeting Renewable Portfolio Standard (RPS) goals.
- SCE will place the PV systems on larger commercial rooftops with sufficient size and strength to accommodate approximately 1 to 2 MW of generation.[5] The Solar PV Program will focus, though not exclusively, on those roofs which would typically not employ net energy metering.[6] For example, large warehouse roofs

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[5] While SCE presently intends the program for rooftops, SCE may pursue other locations and opportunities for placement of Solar PV facilities.

[6] Net energy metering solar installations, which are limited to 1 MW, allow eligible utility customers to receive CSI incentives and off-set their energy usage by their solar PV system output over a 12-month period.

with little on-site load would not typically employ net energy metering. In doing so, the Solar PV Program will utilize underused rooftops to the State of California's benefit.

- These solar PV systems should not require any transmission construction, because they interconnect directly with SCE's distribution system. So, Solar PV Program power development can move forward more quickly than other forms of renewable generation that depend on construction of new transmission facilities.
- Large scale implementation of about 50 MW of solar PV projects each year will likely introduce efficiencies to the California market for rooftop solar PV generation. The goals are to drive installation costs down, improve technology and pricing of certain component parts, increase installation efficiency, and improve installation methods.
- SCE, as the owner of the Solar PV Program, will capture its output on behalf of its bundled service customers to meet the State's renewable goals.
- SCE is a reliable business partner who can assure implementation and administration of the Solar PV Program. The Solar PV Program provides SCE's customers and the State with a substantial increase in the probability that 250 MW of solar PV rooftop systems will be available to meet State policies and goals supporting solar PV development over the next five years.
- SCE will increase recognition and acceptance of Energy Efficiency (EE) by referring owner/developers of new structures to its EE group to identify potential EE measures that could be incorporated into new structures during construction.
- Ratemaking will allow recovery of reasonable capital and O&M costs as incurred; and
- Immediate start-up of the Solar PV Program will support up to 50 MW of solar PV systems becoming available within one year following Commission approval of this application.

III.

NEED FOR PROJECT AND PROJECT DESCRIPTION

A. Need for Project

1. Solar PV Program Complements The Existing California Solar Initiative (CSI) And Renewable Portfolio Standard Programs

In 2006, Governor Schwarzenegger, working with the Commission and the California Legislature, established a CSI designed to develop 3,000 MW of rooftop solar PV installations by 2016. The State has authorized substantial incentives to achieve this aggressive target of 1 million solar rooftop facilities.

Solar PV is a renewable resource. The State has adopted one of the most aggressive RPS programs in the country. The goal is to have 20% of customer energy needs met with renewable resources.[7] Although not specifically targeted at solar resources, this RPS program has the potential to yield substantial development of large central station solar resources over the next decade. Several large-scale, central station solar installations are already under contract or in development as a result of SCE's RPS program.

But these programs have arguably left a large solar PV gap. California's CSI program is geared to develop very small solar PV installations. California's RPS program is presently geared to develop very large solar (not necessarily PV) installations. Neither program, however, is well suited to develop medium-scale PV solar installations in the 1 to 2 MW range in the near-term due to size and transmission limitations. And although the economics of 1 to 2 MW facilities are far superior to typical rooftop facilities, they are too large to take full

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[7] Public Utilities Code Section 399.15(b)(1) sets forth a goal that 20% of retail electric sales be served by renewable resources by 2010:

> Each retail seller shall, pursuant to subdivision (a), increase its total procurement of eligible renewable resources by at least an additional 1% of retail sales per year so that 20% of its retail sales are procured from eligible renewable energy resources no later than December 31, 2010….

advantage of the State's CSI and net energy metering programs. Many large commercial rooftops have site electrical loads that do not match the energy production of a 1 to 2 MW solar PV facility. Conversely, other utility-scale solar technologies, such as parabolic trough, Stirling dish, and "power tower" installations are not commercially practicable for rooftop installations at the 1 to 2 MW scale. SCE's Solar PV Program fills this solar gap, because this bandwidth of the solar resource is, as yet, going untapped. There is currently no program in place to develop this market sector. SCE proposes immediate start-up of the Solar PV Program to assist in meeting the State's rooftop solar goals and to bridge the gap.

SCE's Solar PV Program is targeted at the vast untapped resource of commercial and industrial rooftop space in SCE's service territory. This program will aggressively bridge the gap between small and large scale solar installations. Although this program will focus on a fertile market sector undeveloped by either the CSI or RPS programs, the program will contribute to meeting both goals. In CSI terms, this program has the potential to add over 80,000 "rooftop equivalents"[8] in five years or about 10 % of the overall CSI goal of 1 million rooftops. SCE's program will also contribute in the near term to achieving the State's renewable energy goals. Because these installations will interconnect at the distribution level, they can be brought on line relatively quickly without the need to plan, permit, and construct the transmission lines. Larger scale renewable resources generally require transmission line construction to deliver their output to load centers.

SCE is currently pursuing transmission line permitting and construction as one way to help the State meet its renewable energy goals. In addition, SCE's actions to implement its Long Term Procurement Plan (LTPP) and RPS procurement are aimed at advancing the State's renewable energy goals. Decision No. (D).06-05-039 states that "…, we will take into account whether or not each electrical corporation undertook all reasonable actions to comply [in

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[8] The State's CSI goal of 3,000 MW by 2016 is based on an average PV installation size of 3 kW, yielding 1 million rooftops. A "rooftop equivalent" is 3 kW. SCE's program goal of 250 MW installed by 2013 yields 83,333 rooftop equivalents.

meeting the State's renewable energy goals]. One of those actions is building, then owning and operating the [renewable] resource itself."[9] In addition, D.07-02-011 and D.08-02-008 [10] stated that, "…we encourage IOUs to actively assess the feasibility of utility ownership, and pursue such ownership when and where it makes sense." While the primary purpose of the program is to help meet the State's ambitious solar roof goals, the Solar PV Program will add to SCE's renewable portfolio in response to these challenges. Specifically, in 2009, Solar PV Program installations will produce 0.1% of SCE's customer energy needs; by 2014, Solar PV Program installations will produce approximately 0.4% of SCE's customer energy needs. To assure the availability of this generation as soon as possible after approval of this application, SCE may begin implementation of the Solar PV Program in 2008, while awaiting a final Commission decision on this application.

SCE proposes this program in furtherance of the State's goal to increase the installation of solar PV technology. Our proposed program will achieve this goal at lower cost and will further help jump-start the solar industry. The cost to our customers of the Solar PV Program will be significant, but far less than the cost of CSI implementation. For these reasons, if the CSI goals become mandatory for SCE's customers, SCE requests that the MWs installed under its program be "credited" towards its customers' targets. In addition, the cost impact on our customers is not insubstantial. They already bear the annual cost of the CSI program and the carrying costs of the Solar PV program if SCE's application is granted. This may justify reducing their share of the State's CSI goals and potentially some portion of the CSI program costs our customers contribute.

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[9] D.06-05-039, *mimeo,* p. 34

[10] D.07-02-011, *mimeo,* p. 25 and D.08-02-008, *mimeo,* p. 33

2. SCE Can Best Develop Solar PV Program

SCE, as the operator of its distribution system, has the technical expertise to thoroughly and fairly evaluate the various solar PV technologies and the impacts on its distribution system. SCE will claim the output of the Solar PV Program as renewable energy on behalf of its bundled service customers to help meet SCE's renewable goals.

SCE can effectively monitor and cost-effectively facilitate repair of these systems through its field personnel. SCE can also utilize its established electric supply relationships with potential vendors and commercial building lessors who are also its customers. SCE has the ability to utilize established longstanding relationships with these entities over the 100 plus years that SCE has been in business. Those counterparties view SCE as a stable, competent, and reliable business. SCE's strong balance sheet and procurement expertise allows it to negotiate reasonable contracts with rooftop owners and vendors.

SCE expects that through negotiations with vendors it can obtain volume discounts for its proposed base case investment of $875 million. Most solar PV developers are unlikely to achieve these same efficiencies and pricing levels. SCE's Solar PV Program will move quickly because of its established relationships with key players. According to CSI data, more than 40% of the applications for projects over 900 kW in SCE's service territory have been cancelled or suspended since CSI was implemented in January 2007. In addition, most solar PV developers have been in business for only a few years. Given the size and proposed rollout of the Solar PV Program, SCE uniquely can provide customers and the State a substantial increase in the probability that 250 MW of solar PV systems will be available to meet the State goals over the next five years.

SCE can coordinate the Solar PV Program with customer demand shifting using existing SCE demand reduction programs on the same circuit. This will create more fully utilized distribution circuit assets. Without such coordination, much more distribution equipment may be needed to increase solar PV deployment. SCE is uniquely situated to combine Solar PV Program generation, customer demand programs, and advanced distribution

circuit design and operation into one unified system. This is more cost-effective than separate and uncoordinated deployment of each element on separate circuits.

Finally, SCE, as a regulated public utility is willing to share the results of its experience with solar PV with other entities in the State. Specifically, SCE will share information about: (1) how solar PV systems of 1 to 2 MW interface with SCE's distribution system; (2) forecasting and scheduling of solar PV generating facilities of 1 to 2 MW disbursed throughout SCE's inland service territory; (3) training and increasing efficiency of the skilled workforce for installation and maintenance of these facilities including development of best installations practices for 1 to 2 MW solar PV projects; and (4) potential streamlining and revision of tariff applications, local and State codes. These publicly shared "lessons learned" will benefit the entire PV industry. The information collected by SCE will provide useful knowledge and best practices to other entities which increase the efficiency of all solar PV installations in California.

3. The Solar PV Program Could Drive Costs Down And Increase Efficiencies

SCE's 50 MW of solar PV facilities each year could: (1) refine production of parts, (2) improve the capabilities of ancillary equipment, (3) make use of vacant commercial rooftops in California, and (4) increase the efficiency of installation of PV systems. To meet the ambitious goals of the Solar PV Program, SCE will order large numbers of solar PV mounting and electrical connection parts each year. The increased scale of manufacturing required by such orders should lead manufacturers to improve designs and to increase their efficiency and capability to produce such parts. Manufacturers will also likely have the economic incentive to improve manufacturing processes to incorporate economies of scale that drive prices down.

SCE's Solar PV Program will also expand the number of skilled workers by increasing the number of installations of solar PV systems of 1 to 2 MW. Skilled workers will gain efficiency and knowledge simply by repetitively performing installations. Labor is

currently about 20% of the cost of any solar PV installation. SCE should drive costs of solar PV installation lower by improving the efficiency of workers.

The purpose of the Solar PV Program is to create efficiencies in the California solar PV market by providing a market for 1 to 2 MW solar PV systems. This will give SCE and California much more experience with such systems. Utilities throughout the United States can use the experience gained in California as a model for their own Solar PV development programs.

B. Project Description

1. The Solar PV Program Will Provide Up To 250 MW Of Renewable Generation Over The Next Five Years

SCE contemplates that Solar PV Program's first five years would yield about 50 MW in total each year of installations of 1 to 2 MW solar PV facilities. Over the first five years, this would total 250 MW. SCE seeks to create efficiencies in the California market for solar PV equipment and installation resources, but, at the same time, to not overheat the market for solar PV panels, equipment, and installation resources. In SCE's judgment, 50 MW per year should trigger new efficiencies, but not drive prices up due to materials shortages.[11]

It should be noted that the Solar PV Program installation goals are all based on the PV industry convention of using direct current (dc) output. The power output figures referenced in this document, unless otherwise noted, refer to manufacturer's panel dc ratings. As discussed in SCE's testimony, SCE has chosen a conversion factor from dc to alternating current (ac) output of 0.90 based on sample calculations. Using this conversion factor, a 1 MW dc facility converts to 900 kW ac facility.

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[11] If the program is successful, SCE may seek Commission authority to increase the overall size of the Solar PV Program to 500 MW. The additional 250 MW would likely be realized through the combination of installing more MW per year and lengthening the program term itself.

All costs and sizing of solar PV facilities described in this application are based on dc power. The entire solar PV industry historically bases costs and sizing on dc power. SCE must convert generally, the dc power to ac power for use on its distribution system. Inverters perform this conversion. Inverters also control the interface between the solar array and the distribution grid. Inverters are currently available in various sizes up to 500 kilowatts (kW) ac for large systems. The Solar PV Program should lead to improvements in inverter technology by increasing orders for these components and by testing their usefulness to the distribution grid.

Solar PV systems also include conduit, wire, dc and ac disconnects (safety devices to turn off or isolate parts of the system) and combiner boxes. Most solar PV systems require some type of attachment method. This product is typically called a rack. The Solar PV Program will utilize only non-penetrating racks which sit on top of the roof. Non-penetrating racks require some weight to be added to the rack (ballasted) or primarily rely on the weight of the rack and modules themselves to hold the array in place (non-ballasted).

2. Use of Rooftop Space for Facilities

SCE intends to install up to 250 MW of 1 to 2 MW solar PV facilities on commercial building rooftops at various locations within SCE's service territory. The proposed 1 to 2 MW facility per location will require up to about 250,000 square feet of useable rooftop space in each location. For this Solar PV Program, SCE will look to a limited number of building owner/developers to provide an inventory of appropriate locations. This process should more efficiently select appropriate locations and reduce the time from locating the site to installation by limiting the number of simultaneous lease negotiations.

SCE will develop methods to determine the optimal location for the solar PV facilities. SCE will consider: (1) quality of the local solar resources by estimating expected PV generation based on factors such as expected cloud/fog cover, haze and smog, ambient temperature, and geographical latitude and other meteorological data, (2) roof capacity and other building attributes, and (3) local distribution circuit concerns. To determine the quality of the

local solar resource, SCE will rely on the National Renewable Energy Lab (NREL) database that provides information about the highest quality local resources down to 10 kilometer (km) grids. SCE will also consider other relevant meteorological data.

SCE must also consider the ability of the commercial rooftops to handle the additional weight loading which can vary based on the technology employed. In general, the roofs must hold an additional 3 to 5 pounds per square foot. SCE will also identify customers owning buildings that typically would not benefit from net energy metering. SCE will also take into account the ease of local permitting and the availability of ground space to install inverters and transformers, which are too heavy to install on a roof.

SCE will also refer owner/developers of new buildings seeking to participate in the Solar PV Program to its EE group. SCE's EE group can then identify potential EE measures to be incorporated into the building's design. This will increase awareness and acceptance of the benefits of EE measures among building owners/developers.

3. Program Costs

Solar PV Program costs include: (1) capital costs of initial installation of the 1 to 2 MW solar PV facilities; and (2) the O&M costs, including roof lease payments, other O&M and staffing costs. Solar PV Program installation costs are likely to be lower than those of a single 1 to 2 MW solar PV facility because of economies of scale. SCE's consistent purchases of solar PV components and installation services should drive costs down by improving technology of component parts and improving efficiency of skilled work forces.

a) Capital

Table III-1 below contains SCE's base case estimate of the capital costs of Solar PV Program over the five-year period.

Table III-1
Solar PV Program Estimated Base Case Capital Costs
(2008$ 000)

Year	Capital (Million $)	MW Installed	Estimated Time Frame
0	$25	5	2008
1	$174	50	2009
2	$174	50	2010
3	$174	50	2011
4	$174	50	2012
5	$154	45	2013
Total	$875	250	

The Solar PV Program base case direct capital cost forecast is $875 million. The average cost of the solar PV facilities should be about $3.50/W.[12] At present, the average cost of solar PV facilities above 900 kilowatts (kW) range from $6.56-7.08/W. SCE anticipates achieving lower costs than the present average through economies of scale and improvements in technology and efficiency.

b) **O&M Costs**

As noted previously, O&M costs consist of three components: (1) roof lease payments; (2) other O&M costs; and (3) SCE staffing costs. With regard to the roof lease payments, this is a new opportunity for the large rooftop owners. So, it is difficult to estimate expected leasing rates. However, SCE anticipates that the maximum price paid for these roof

[12] On average, the reasonableness threshold is 10% higher than the base case estimate or about $3.85/W. The reasonableness threshold is higher than this amount in early years of the Solar PV Program and lower in later years, as shown in Table IV-2 below.

leases will be a small percentage of the value of the electricity produced. It is difficult to effectively estimate the roof lease payments until SCE has negotiated at least one rooftop lease. Moreover, identifying an expected lease cost prior to lease negotiations could prejudice lease negotiations to the detriment of SCE's customers. The estimated Other O&M costs for a 1 MW solar PV facility are $35,000 per year. For a 2 MW solar PV facility, these Other O&M costs would be roughly double the amount required for a 1 MW system. The SCE annual staffing costs to run the Solar PV Program are forecast to be $1.4 million at full deployment.

IV.

PROPOSAL FOR COST RECOVERY

A. The Commission Should Adopt SCE's Proposed Solar PV Program Balancing Account (SPVPBA) For Rate Recovery of Solar PV Program Costs

SCE requests that the Commission provide rate recovery of Solar PV Program costs through its proposed SPVPBA. The SPVPBA will ensure that no more and no less than reasonable actual costs associated with the Solar PV Program are ultimately recovered from customers.[13] Balancing account treatment is appropriate for this type of renewable resource. The Solar PV Program costs ramp up over time. The program should introduce efficiencies into the California solar PV market. SCE expects solar PV costs to go down as a result of the Solar PV Program. Cost estimates, therefore, are likely to be difficult to predict during this period.

The SPVPBA would operate through the 2009-2013 program period. The SPVPBA would end with the inclusion of both Solar PV Program O&M and capital revenue requirements in SCE's Test Year 2015 General Rate Case (GRC) revenue requirement or sooner.

Concurrent with this filing, SCE will file an advice letter requesting Commission authority to establish a Solar PV Program Memorandum Account (SPVPMA). SCE will record

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[13] By paying for these costs, SCE's bundled service customers would see a reduction in their energy procurement costs reflected in SCE's Energy Resource Recovery Account (ERRA) revenue requirement because SCE would not need to procure the equivalent amount of energy from other sources.

start-up costs associated with the Solar PV Program in the SPVPMA while this application is pending. SCE estimates start-up direct capital costs to be $25 million in 2008. If the Commission does not act on this application in 2008, SCE may record the revenue requirement for capital costs above $25 million in the SPVPMA. The SPVPMA is necessary to ensure that the Solar PV Program can proceed without delay and without precluding cost recovery at a future date. Similar to all Commission-approved memorandum accounts, the SPVPMA will protect against retroactive ratemaking concerns, but will not guarantee rate recovery of any recorded costs prior to Commission review and approval. Once the Commission approves SCE's request to establish the SPVPBA in this application, SCE will transfer the balance recorded in the SPVPMA to the SPVPBA.

B. The Commission Should Adopt SCE's Proposed Reasonableness Standard For These Clean, Renewable Generation Resources

SCE proposes to include testimony supporting the reasonableness of the Solar PV Program O&M costs recorded in the SPVPBA during the prior calendar year in its annual April Energy Resources Recovery Account (ERRA) reasonableness proceeding. If its Solar PV Program capital expenditures in each calendar year of the program, on a per W basis, are less than the amounts shown in Table IV-2 below, then capital expenditures would be deemed to be reasonable.

Table IV-2
Reasonableness Review Threshold For Solar PV Program Direct Capital Costs (2008$)[14]

Expenditures Incurred During	**$/W**
2008	5.50
2009	3.83
2010	3.83
2011	3.83
2012	3.83
2013	3.76

The capital expenditure threshold levels in Table IV-2 are reasonable because they represent SCE's base case estimate of Solar PV Program costs of $875 million plus a reasonable 10% contingency to take total reasonable costs up to $962.5 million.

In any year that SCE's direct capital expenditures, on a $/W basis on average, exceed the amounts in Table IV-2 above, as escalated. SCE will include in its annual April ERRA reasonableness proceeding testimony supporting the reasonableness of the capital expenditures during the previous calendar year. Even if no reasonableness testimony for capital expenditures is required, SCE will include the Solar PV Program costs in its annual April ERRA reasonableness proceeding. This will allow the Commission to audit and review the O&M and capital revenue requirement recorded in the SPVPBA.

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[14] These threshold amounts will be escalated to nominal year amounts for use in reasonableness review.

V.

THIS APPLICATION FOR RECOVERY OF THE SOLAR PV PROGRAM'S COST IS EXEMPT FROM CEQA REVIEW

It is long established that the act of ratemaking by the Commission is exempt from CEQA review. As stated in the California Public Resources Code, the "establishment, modification, structuring, restructuring, or approval of rates, tolls, fares, or other charges by public agencies" including "obtaining funds for capital projects necessary to maintain service areas" is exempt from CEQA.[15]

Further, agencies such as the Commission may dispense with CEQA review "if it can be seen with certainty that there is no possibility that the activity in question may have a significant effect on the environment"[16] In this case, it is clear that the activity of installing rooftop PV systems would not have a significant effect on the environment. First, the nature of SCE's proposed Solar PV Program dictates that installations would not be undertaken in residential areas. Instead, installations would likely take place on large warehouse/distribution buildings located in industrial areas. Further, none of the rooftop arrays would be visible from street level angles and building parapets would contribute to the arrays being hidden from view. In addition the inverter systems would either be located within building electrical rooms or would otherwise be located next to buildings in an obtrusive manner. As a result, the installation of rooftop PV systems will not have a significant effect on the environment.

The evidence that the installation of rooftop PV systems would not have a significant effect on the environment is bolstered by the fact that rooftop PV systems do not require local discretionary approvals. Instead, the installation of PV Facilities on rooftops in the contemplated locations can be accomplished through the application for and acquisition of local,

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[15] Cal. Pub. Resources Code Section 21080 (b)(8)

[16] CEQA Guidelines Section 15061 (b) (3)

non-discretionary, building permits.[17] As a result, the installation of PV systems on rooftops by SCE is not subject to local review under CEQA[18]. Even if the installation of PV systems on rooftops were subject to CEQA review, at this early planning stage, SCE is uncertain as to the PV rooftop system installation locations, and as a result there would be no ability to perform any CEQA analysis at a local level review.

Under the California Solar Rights Act,[19] local governments are precluded from adopting ordinances that would unreasonably restrict the use of solar energy systems in residential and commercial capacities. The section also states that it is the intent of the Legislature to prohibit local governments from adopting ordinances that "create unreasonable barriers to the installation of solar energy systems, including but not limited to, design review for aesthetic purposes…"[20] The Act also requires that local governments use a non-discretionary permitting process for solar energy systems[21] State law requires that this non-discretionary review process be limited to "those standards and regulations necessary to ensure that the solar energy system will not have a specific, adverse impact upon the public health or safety"[22] Fundamentally, the Act prevents cities and counties from denying solar energy system building permits unless there is substantial recorded evidence that it would have a specific, adverse impact on public health and safety. If the local permitting agency found that the potential for an adverse impact existed, it could require that a discretionary permit be issued.[23] In such a case, however, SCE would not pursue the installation of PV Facilities. Since SCE would not pursue the installation of PV Facilities in

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[17] If SCE were installing PV systems in a Coastal Zone, Coastal Commission permitting may be required. SCE does not intend to install PV systems in Coastal Zones.

[18] Cal. Pub. Resources Code Section 21080, subds. (a) (b)(1)

[19] The Solar Rights Act is comprised of the following California Codes: Civil Code Sections 714 and 714.1, Civil Code Section 801 and 801.5, Government Code Section 65850.5, Health and Safety Code Section 17959.1, Government Code Section 66475.3 and Government Code Section 66473.1

[20] Govt. Code Section 65850.5

[21] See, Govt. Code Section 65850.5 (a) and Health and Safety Code Section 17959.1

[22] Govt. Code Section 65850.5 (b)

[23] Govt. Code Section 65850.5 (c)

instances where a discretionary permit would be required, the installation of the SCE PV Facilities is not subject to local CEQA review.

Even though this ratemaking is exempt from CEQA review, and the installation of PV Facilities is exempt from CEQA review, such facilities must still comply with all "applicable safety and performance standards established by the National Electric Code, the Institute of Electrical and Electronics Engineers and accredited testing laboratories such as Underwriters Laboratories, and the rules of the Public Utilities Commission regarding safety and reliability."[24]

VI.

STATUTORY AND PROCEDURAL REQUIREMENTS

A. Statutory and Procedural Authority

Rule 2.1 requires that all applications: (1) clearly and concisely state authority or relief sought; (2) cite the statutory or other authority under which that relief is sought; and (3) be verified by the applicant. Rule 2.1 sets forth further requirements that are addressed separately below. The relief being sought is summarized in Sections I (Summary of Request) and VIII (Conclusion), and is further described in the testimony accompanying this application. The statutory and other authority under which this relief is being sought include California Public Utilities Code Sections 451, 454, 454.3, 491, 701, 728, 729, Article 2 and Rule 3.2 of the Commission's Rules of Practice and Procedure, and prior decisions, orders, and resolutions of this Commission. This application has been verified by an SCE officer as provided in Rules 1.11 and 2.1.

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[24] Govt. Code Section 65850.5(f) (3)

B. Rule 2.1

Rule 2.1 requires that applications shall state "the proposed category for the proceeding, the need for hearings, the issues to be considered, and a proposed schedule." These requirements are discussed below.

1. Proposed Categorization

SCE proposes to characterize this proceeding as "ratesetting" as defined in the Commission's Rules of Practice and Procedure, Rule 1.3(e) and Public Utilities Code §1701.1 (c)(3).

2. Need for Hearings and Proposed Schedule for Resolution of Issues

SCE's proposed schedule assumes that there will be evidentiary hearings and briefing.

If the Commission believes evidentiary hearings are necessary, then SCE proposes the following schedule. This schedule will provide for a Commission decision by year end 2008, which will enable SCE to limit capital expenditures prior to Commission approval to $25 million.

SCE files Application	March 27, 2008
Daily Calendar Notice Appears	March 27, 2008
Protests Due	April 28, 2008
Reply to Protests	May 8, 2008
Prehearing Conference	May 15, 2008
ORA and Intervenors File Opening Testimony	June 16, 2008
Rebuttal Testimony Due	June 30, 2008
Hearings	July 7-11, 2008
Concurrent Opening Briefs Due	August 4, 2008
Concurrent Reply Briefs Due	August 16, 2008
Commission Issues Proposed Decision	November 1, 2008
Comments to Proposed Decision Due	December 1, 2008
Replies to Comments to Proposed Decision	December 8, 2008
Commission issues Final Decision	December 18, 2008

3. Issues to be Considered

The issues to be considered in this proceeding are described above and set forth in greater detail in SCE's testimony in support of this application. Major issues include:

a) Whether to approve the implementation of SCE's Solar PV Program and authorize funding; and

b) Whether to adopt SCE's proposed ratemaking treatment for the recovery of the costs associated with the implementation of SCE's Solar PV Program.

4. Legal Name and Correspondence

Southern California Edison Company is an electric public utility organized and existing under the laws of the State of California. The location of SCE's principal place of business is 2244 Walnut Grove Avenue, Post Office Box 800, Rosemead, California 91770. SCE's attorneys in this matter are Douglas K. Porter, Carol A. Schmid-Frazee and Annette Gilliam. Correspondence or communications regarding this application should be addressed to:

Carol A. Schmid-Frazee
Senior Attorney
Southern California Edison Company
P.O. Box 800
2244 Walnut Grove Avenue
Rosemead, California 91770
Telephone: (626) 302-1337
Facsimile: (626) 302-1935
e-mail: carol.schmidfrazee@sce.com

To request a copy of this application, please contact:

Melissa Schary
Southern California Edison Company
P.O. Box 800
2244 Walnut Grove Avenue
Rosemead, California 91770
Telephone: (626) 302-6509
Facsimile: (626) 302-3119
E-mail: melissa.schary@sce.com

C. Articles of Incorporation – Rule 2.2

A copy of SCE's Certificate of Restated Articles of Incorporation, effective on March 2, 2006, and presently in effect, certified by the California Secretary of State, was filed with the Commission on March 14, 2006, in connection with Application No. 06-03-020, and is by reference made a part hereof.

Certain classes and series of SCE's capital stock are listed on a "national securities exchange" as defined in the Securities Exchange Act of 1934 and copies of SCE's latest Annual Report to Shareholders and its latest proxy statement sent to its stockholders has been filed with the Commission.

D. Authority to Increase Rates – Rule 3.2

Rule 3.2 requires that applications for authority to increase rates, or to implement changes that would result in increased rates, contain the following data.

1. Balance Sheet and Income Statement – Rule 3.2(a)(1)

Appendix A to this application contains copies of SCE's balance sheet as of December 31, 2007, and income statement for the period ended December 31, 2007, the most recent period available.

2. Present and Proposed Rates – Rule 3.2(a)(2) and (a)(3)

The cost recovery mechanism proposal is summarized in Section IV above. The cost recovery mechanism proposal and the projected impact on rates are discussed in Exhibit SCE-1.

3. Description of SCE's Service Territory and Utility System – Rule 3.2(a)(4)

Because this submittal is not a general rate application, this requirement is not applicable.

4. Summary of Earnings – Rule 3.2(a)(5)

Rule 3.2(a)(5) requires:

> A summary of earnings (rate of return summary) on a depreciated rate base for the test period or periods upon which applicant bases its justification for an increase.

SCE's 2007 Summary of Earnings is attached hereto as Appendix B.

5. Depreciation – Rule 3.2(a)(7)

Because this submittal is not a general rate application, this requirement is not applicable.

6. Capital Stock and Proxy Statement – Rule 3.2(a)(8)

Because this submittal is not a general rate application, this requirement is not applicable.

7. Statement Pursuant to Rule 3.2(a)(10)

Rule 3.5(a)(10) requires the applicant to state whether its request is limited to passing through to customers "only increased costs to the corporation for the services or commodities furnished by it." This application seeks only to pass through to SCE's customers the costs incurred by SCE in its Solar PV Program.

8. Service of Notice – Rule 3.2(b), (c) and (d)

A list of the cities and counties affected by the rate changes resulting from this application is attached as Appendix C. The State of California is also an SCE customer whose rates would be affected by the proposed revisions.

As provided in Rule 3.2(b) – (d), notice of filing of this application will be: (1) mailed to the appropriate officials of the state and the counties and cities listed in Appendix C; (2) published in a newspaper of general circulation in each county in SCE's service territory within which the rate changes would be effective; and (3) mailed to all customers affected by the proposed changes.

E. Service List

SCE is serving this application and its exhibits on all parties on the Commission's service lists for proceedings A.07-11-011 and R.08-02-007.

VII.

CONCLUSION

SCE respectfully requests that the Commission:

(1) Find it reasonable for SCE to implement the Solar PV Program consisting of the installation of up to 250 MW of utility-owned solar PV generating facilities (of approximately 1 to 2 MW each) over the next five years;

(2) Establish ratemaking for SCE for the Solar PV Program, specifically including:

a) Provision for each solar 1 to 2 MW PV facility to receive rate-base recovery upon its completion, subject to adjustment following reasonableness review if direct capital expenditures exceed certain $/W thresholds each year on average; and

b) Provision for recovery of reasonable Operation and Maintenance (O&M) expenses.

(3) Establish an annual estimate of average reasonable capital costs, based on $/W threshold, below which no reasonableness review is required;

(4) Require SCE to refer the owner/developer of new structures seeking to participate in the Solar PV Program to SCE's Energy Efficiency group to identify potential energy efficiency measures that could be incorporated into new structures;

(5) Find that SCE's proposed Solar PV Program will not require CEQA[25] review at this Commission;

(6) Establish a balancing account for recovery of all Solar PV Program costs subject to annual reasonableness review of O&M expenses and reasonableness review of capital expenditures only if capital expenditures exceed a certain $/W reasonableness threshold on average in a given year;

(7) Establish, through a resolution approving SCE's concurrently filed Advice Letter, a new memorandum account. This will provide a mechanism for recovery of 100% of reasonable start-up costs for the Solar PV Program. If the Commission disapproves the remainder of SCE's application, SCE may request recovery of actually incurred capital expenditures and O&M costs. SCE estimates capital expenditures of $25 million in 2008. If the Commission does not act on this application in 2008, SCE will continue to record the revenue requirement for the Solar PV Program costs in the memorandum account in 2009; and

(8) Adopt any other measures necessary to support SCE's Solar PV Program.

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[25] Cal. Public Resources Code §§21000, et seq.

Dated this 27th day of March 2008, at Rosemead, California.

Respectfully submitted,

SOUTHERN CALIFORNIA EDISON COMPANY

/s/ Richard M. Rosenblum

By: Richard M. Rosenblum
Executive Vice President

DOUGLAS K. PORTER
CAROL A. SCHMID-FRAZEE
ANNETTE GILLIAM

/s/ Carol A. Schmid-Frazee
By: Carol A. Schmid-Frazee

Attorneys for
SOUTHERN CALIFORNIA EDISON COMPANY

2244 Walnut Grove Avenue
Post Office Box 800
Rosemead, California 91770
Telephone: (626) 302-1337
Facsimile: (626) 302-1935
E-mail:carol.schmidfrazee@sce.com

March 27, 2008

VERIFICATION

I am an officer of the applicant corporation herein, and am authorized to make this verification on its behalf. I am informed and believe that the matters stated in the foregoing document are true.

I declare under penalty of perjury that the foregoing is true and correct.

Executed this **27th day of March, 2008**, at Rosemead, California.

/s/ Richard M. Rosenblum
Richard M. Rosenblum
Executive Vice President
SOUTHERN CALIFORNIA EDISON COMPANY
2244 Walnut Grove Avenue
P.O. Box 800
Rosemead, CA 91770

Appendix A

Southern California Edison Company's

Balance Sheet and Income Statement

SOUTHERN CALIFORNIA EDISON COMPANY

BALANCE SHEET

DECEMBER 31, 2007

A S S E T S

(Millions of Dollars)

UTILITY PLANT:	
Utility plant, at original cost	$20,707
Less - Accumulated depreciation and decommissioning	(5,174)
	15,533
Construction work in progress	1,693
Nuclear fuel, at amortized cost	177
	17,403
OTHER PROPERTY AND INVESTMENTS:	
Nonutility property - less accumulated provision for depreciation of $701	1,000
Nuclear decommissioning trusts	3,378
Other Investments	69
	4,447
CURRENT ASSETS:	
Cash and equivalents	252
Margin and collateral deposits	37
Receivables, including unbilled revenues, less reserves of $34 for uncollectible accounts	725
Accrued unbilled revenue	370
Inventory	283
Accumulated deferred income taxes - net	146
Derivative assets	54
Regulatory assets	197
Other current assets	188
	2,252
DEFERRED CHARGES:	
Regulatory assets	2,721
Derivative assets	28
Other long-term assets	629
	3,378
	$27,480

SOUTHERN CALIFORNIA EDISON COMPANY

BALANCE SHEET

DECEMBER 31, 2007

CAPITALIZATION AND LIABILITIES

(Millions of Dollars)

CAPITALIZATION:	
Common stock	$2,168
Additional paid-in capital	507
Accumulated other comprehensive loss	(15)
Retained Earnings	3,568
Common shareholder's equity	6,228
Preferred and preference stock not subject to redemption requirements	929
Long-term debt	5,081
	12,238
CURRENT LIABILITIES:	
Short-term debt	500
Accounts payable	914
Accrued taxes	42
Accrued interest	126
Counterparty collateral	42
Customer deposits	218
Book overdrafts	204
Derivative liabilities	100
Regulatory liabilities	1,019
Other current liabilities	548
	3,713
DEFERRED CREDITS:	
Accumulated deferred income taxes - net	2,556
Accumulated deferred investment tax credits	105
Customer advances	155
Derivative liabilities	13
Power purchase contracts	22
Accumulated provision for pensions and benefits	786
Asset retirement obligations	2,877
Regulatory liabilities	3,433
Other deferred credits and other long-term liabilities	1,136
	11,083
Minority interest	446
	$27,480

SOUTHERN CALIFORNIA EDISON COMPANY

STATEMENT OF INCOME

YEAR ENDED DECEMBER 31, 2007

(Millions of Dollars)

OPERATING REVENUE	$10,478
OPERATING EXPENSES:	
Fuel	1,191
Purchased power	3,124
Provisions for regulatory adjustment clauses - net	271
Other operation and maintenance expenses	2,840
Depreciation, decommissioning and amortization	1,094
Property and other taxes	217
Total operating expenses	8,737
OPERATING INCOME	1,741
Interest income	44
Other nonoperating income	89
Interest expense - net of amounts capitalized	(429)
Other nonoperating deductions	(45)
INCOME BEFORE TAX AND MINORITY INTEREST	1,400
INCOME TAX EXPENSE	337
MINORITY INTEREST	305
NET INCOME	758
DIVIDENDS ON PREFERRED AND PREFERENCE STOCK - NOT SUBJECT TO MANDATORY REDEMPTION	51
NET INCOME AVAILABLE FOR COMMON STOCK	$707

Appendix B

Southern California Edison Company's

2008 Summary of Earnings

Southern California Edison
Summary of Earnings
2008 GRC-Related Adopted Revenue Requirement [1/]
Thousands of Dollars

Line No.	Item	Total
1.	**Base Revenues**	4,113,324
2.	**Expenses:**	
3.	Operation & Maintenance	1,874,463
4.	Depreciation	882,131
5.	Taxes	617,599
6.	Revenue Credits	(170,624)
7.	Total Expenses	3,203,569
8.	**Net Operating Revenue**	909,755
9.	**Rate Base**	10,397,198
10.	**Rate of Return**	8.75%

1/ D.06-05-016/Advice Letter 2176-E and 2196-E
Includes one SONGS 2&3 refueling and maintenance outage

Appendix C

List of Cities and Counties

SOUTHERN CALIFORNIA EDISON COMPANY

Citizens or some of the citizens of the following counties and municipal corporations will or may be affected by the changes in rates proposed herein.

COUNTIES

Fresno	Kings	Orange	Tuolumne*
Imperial	Los Angeles	Riverside	Tulare
Inyo	Madera	San Bernardino	Ventura
Kern	Mono	Santa Barbara	

MUNICIPAL CORPORATIONS

Adelanto	Cudahy	La Habra	Ojai	Santa Monica
Agoura Hills	Culver City	La Habra Heights	Ontario	Santa Paula
Alhambra	Cypress	La Mirada	Orange	Seal Beach
Aliso Viejo	Delano	La Palma	Oxnard	Sierra Madre
Apple Valley	Desert Hot Springs	La Puente	Palm Desert	Signal Hill
Arcadia	Diamond Bar	La Verne	Palm Springs	Simi Valley
Artesia	Downey	Laguna Beach	Palmdale	South El Monte
Avalon	Duarte	Laguna Hills	Palos Verdes Estates	South Gate
Baldwin Park	El Monte	Laguna Niguel	Paramount	South Pasadena
Barstow	El Segundo	Laguna Woods	Perris	Stanton
Beaumont	Exeter	Lake Elsinore	Pico Rivera	Tehachapi
Bell	Farmersville	Lake Forest	Placentia	Temecula
Bell Gardens	Fillmore	Lakewood	Pomona	Temple City
Bellflower	Fontana	Lancaster	Port Hueneme	Thousand Oaks
Beverly Hills	Fountain Valley	Lawndale	Porterville	Torrance
Bishop	Fullerton	Lindsay	Rancho Cucamonga	Tulare
Blythe	Garden Grove	Loma Linda	Rancho Mirage	Tustin
Bradbury	Gardena	Lomita	Rancho Palos Verdes	Twentynine Palms
Brea	Glendora	Long Beach	Rancho Santa Margarita	Upland
Buena Park	Goleta	Los Alamitos	Redlands	Victorville
Calabasas	Grand Terrace	Lynwood	Redondo Beach	Villa Park
California City	Hanford	Malibu	Rialto	Visalia
Calimesa	Hawaiian Gardens	Mammoth Lakes	Ridgecrest	Walnut
Camarillo	Hawthorne	Manhattan Beach	Rolling Hills	West Covina
Canyon Lake	Hemet	Maywood	Rolling Hills Estates	West Hollywood
Carpinteria	Hermosa Beach	McFarland	Rosemead	Westlake Village
Carson	Hesperia	Mission Viejo	San Bernardino	Westminster
Cathedral City	Hidden Hills	Monrovia	San Buenaventura	Whittier
Cerritos	Highland	Montclair	San Dimas	Woodlake
Chino	Huntington Beach	Montebello	San Fernando	Yorba Linda
Chino Hills	Huntington Park	Monterey Park	San Gabriel	Yucaipa
Claremont	Indian Wells	Moorpark	San Jacinto	Yucca Valley
Commerce	Industry	Moreno Valley	San Marino	
Compton	Inglewood	Murrieta	Santa Ana	
Corona	Irvine	Newport Beach	Santa Barbara	
Costa Mesa	Irwindale	Norco	Santa Clarita	
Covina	La Canada Flintridge	Norwalk	Santa Fe Springs	

*SCE provides electric service to a small number of customer accounts in Tuolumne County and is not subject to franchise requirements.

Appendix D

Background Information on CSI

I.

BACKGROUND INFORMATION ON CSI

1. Background of Solar Efforts in California

Large utility-scale applications of solar PV and other solar powered electric systems date back to 1978, when Congress passed the Public Utility Regulatory Policy Act, or PURPA. PURPA established the right for independent power producers, some of which used solar power, to interconnect with the local utility distribution system. Then Congress passed the Energy Tax Act (ETA) of 1978 in response to the energy crises of the 1970's initiated by the Arab oil embargo and the taking of U.S. hostages in Iran. The ETA encouraged homeowners to invest in energy conservation and solar and wind technologies through tax credits.[26] However, the incentives were phased out in the mid-1980s as a result of federal policies to leave energy conservation and renewable energy decisions up to market conditions. Nevertheless, the federal tax credits spurred the creation of new utility-scale solar.[27]

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[26] A federal energy tax credit of up to $2,000 was given for devices installed on people's homes on or after April 20, 1977 and before January 1, 1986. Solar space and water heating carried a 40% tax credit, while weatherization, insulation, and similar conservation activities carried a 15% tax credit.

[27] Some of the solar projects included:

- In 1979, ARCO Solar began construction of the world's largest PV manufacturing facility in Camarillo, California. ARCO Solar was the first company to produce more than 1 MW of PV modules in one year. Four years later, ARCO Solar dedicated a 6 MW, 120-acre, unstaffed PV facility in central California in the Carrissa Plain, which supplied PG&E's grid with power for about 2,500 homes. ARCO Solar also built a 1 MW PV facility with modules on over 108 double-axis trackers in Hesperia, California.
- In 1981, the Department of Energy, SCE, Los Angeles Department of Water and Power, and the CEC completed Solar One, which was the first test of a large-scale thermal solar tower, power plant. Solar One was located in Daggett, California, and produced 10 MW of electricity from 1982 to 1986.
- In 1984, the Sacramento Municipal Utility District dedicated a 1.0 MW PV facility to operate near the Rancho Seco Nuclear Power Plant south of Sacramento. It was later expanded to 2 MW.
- In 1986, the world's largest solar thermal electricity facility (more than 300 MW of solar thermal electricity) began to be built in California's Mojave Desert. The LUZ Solar Energy Generating Stations contains rows of mirrors that concentrate the sun's energy onto a system of pipes circulating a heat-transfer fluid. The heated transfer fluid produces steam, which powers a conventional turbine to generate electricity. The company had financial difficulties and was eventually sold, but the facility is still producing power today.

Continued on the next page

In 1996, another important event occurred when the Legislature passed and the Governor signed Assembly Bill 1890 (AB 1890). AB 1890 not only deregulated the state's investor-owned electric utilities (IOUs), but it also created incentives for grid-tied PV systems under the CEC's Renewable Energy Program (REP). In 1997, the Legislature passed Senate Bill 90 (SB 90), which implemented the provisions of AB 1890 and directed the activities of the CEC relating to renewable energy. The primary goal of this program was to develop a self-sustaining market for "emerging" renewable energy technologies in distributed generation applications. The Emerging Renewables Program (ERP) was created to stimulate market demand for renewable energy systems that meet certain eligibility requirements by offering rebates to reduce the initial cost of the system to the customer. For systems larger than 30 kW, the CPUC directed IOUs to work with businesses, governments, and schools to install PV "self-generation" systems. In the ten years following 1996, more than 150 MW of electricity was installed through both the CEC's and the CPUC's programs.

On August 20, 2004, Governor Arnold Schwarzenegger laid the groundwork for the CSI Program with initiation of his Million Solar Homes Plan. On December 15, 2005, the CPUC adopted policies and funding for the CSI Program in D.05-12-044. The CPUC found that increasing Small Generator Interconnection Procedure (SGIP) funding for solar projects by $300 million recognized the existing demand for incentives and the need to spur additional solar development.[28] The CPUC also ordered Commission staff to draft a comprehensive proposal for the CSI to be filed in that proceeding.[29]

Continued from the previous page

- In 1993, Pacific Gas and Electric Company installed the first grid-supported photovoltaic system in Kerman, California. The 500-kilowatt system was considered the first "distributed power" PV installation.
- In 1996, the DOE and an industry consortium begin operating Solar Two, which was an upgrade of the Solar One concentrating solar power tower. Until the project's end in 1999, Solar Two demonstrated how solar energy can be stored efficiently and economically, so that power may be is produced even when the sun isn't shining; it also spurred commercial interest in power towers.

[28] D.05-12-044, Finding of Fact No. 3, *mimeo,* p. 11, Conclusion of Law No. 1, *mimeo,* p. 12, and Ordering Paragraph No. 1, *mimeo,* p. 12-13

[29] D.05-12-044, Ordering Paragraph No. 4, *mimeo,* p. 13

2. Implementation of the CSI Program

On January 12, 2006, the CPUC implemented the CSI Program in the SGIP proceeding by D.06-01-024, which created a $2.8 billion, ten-year program to put solar on a million roofs in the state. This program changed the way the state's renewable energy incentives and rebates would be managed. The CPUC's budget for the CSI Program was set at $2.5 billion from 2007 through 2016, to be funded through customer support.[30] The Commission allowed qualifying solar projects to receive CSI incentives for up to 5 MW, which was an increase from the previous 1 MW limit in the SGIP.[31]

On March 2, 2006, the CPUC opened R.06-03-004 to develop rules and procedures for the CSI Program, which had been initiated by D.06-01-024 in R.03-04-017.[32] In R.06-03-004, the CPUC identified the following broad categories of issues to be addressed:

- Resolution of the cost-benefit methodologies explored in R.03-04-017;
- Ongoing management of the SGIP;
- Further development of program rules and policies for the CSI;
- Analysis of subsidies for renewable DG and measurement of renewable DG output for purposes of counting renewable DG output toward the RPS requirements of utilities.[33]

On August 21, 2006, the Governor signed SB 1,[34] which directed the CPUC and the CEC to implement the CSI Program with specific requirements and budget limits set forth in SB 1. SB 1 directed the CEC to establish eligibility criteria for solar energy systems receiving

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[30] The remainder was allocated to the CEC-managed solar programs.

[31] D.06-01-024, *mimeo,* p. 14

[32] In R.03-04-017, the Commission stated its intent to fund a new solar DG program and called the new program the California Solar Initiative. In D.05-12-044, the CPUC provided a total of $342 million for solar incentives in 2006 for the CSI. D.06-01-024, the CPUC committed $2.5 billion to CSI over ten years, established broad program principles and set forth a number of program issues that require our additional attention.

[33] R.06-03-004, *mimeo,* p. 2

[34] SB 1 became effective on January 1, 2007.

customer funded incentives and the CPUC to adopt a performance-based incentive program by January 1, 2008.[35] SB 1 also limited the CPUC's costs for CSI to a total of $2.16 billion and authorized incentives for only the first megawatt of alternating current generated by solar energy systems that meet the eligibility criteria.[36] SB 1 also required the CPUC to publish a schedule of declining incentive levels.[37]

In D.06-08-028, the Commission modified its earlier incentive reduction schedule and adopted an incentive structure that declines only as MW levels of program participation are achieved, rather than after a specified period of time.[38] Each of the incentive "step" reductions adopted by the Commission is larger than 7% and is not linked to a calendar year. In D.06-08-028, the Commission also established a periodic review of CSI to evaluate the average incentive reductions per year in order to make any appropriate adjustments to incentive levels needed to ensure that the SB 1 requirements are being satisfied. Step 2 of the incentive reduction schedule has already begun, since the first 50 MW of solar applications have been reserved. From now on, incentives reserved will be paid at the Step 2 levels until Step 3 is reached.

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[35] SB 1 mandates that by January 1, 2008, the CEC shall consult with the CPUC, local publicly owned electric utilities, and the public to establish certain eligibility criteria for solar energy systems that will receive ratepayer funded incentives. Before that time, SB 1 required the CPUC to determine which solar energy systems were eligible for incentives. SB 1 (2).

[36] SB 1 added Public Utilities Code Section 2851(a)(1), which states that:

> The commission shall authorize the award of monetary incentives for up to the first megawatt of alternating current generated by solar energy systems that meet the eligibility criteria established by the State Energy Resources Conservation and Development Commission pursuant to Chapter 8.8 (commencing with Section 25780) of Division 15 of the Public Resources Code. SB 1, Section 7.

[37] SB 1 adds Section 2851(a)(1) to the Public Utilities Code and states that:

> The incentive level authorized by the commission shall decline each year following implementation of the California Solar Initiative, at a rate of no less than an average of 7 percent per year, and shall be zero as of December 31, 2016. The commission shall adopt and publish a schedule of declining incentive levels no less than 30 days in advance of the first decline in incentive levels. The commission may develop incentives based upon the output of electricity from the system, provided those incentives are consistent with the declining incentive levels of this paragraph and the incentives apply to only the first megawatt of electricity generated by the system.

[38] The Commission also adopted and published a declining solar incentive schedule, with reductions in incentives at the earlier of MW levels of program participation or the start of each calendar year. The incentives declined in 10 steps, with incentives ending on December 31, 2016.

In light of SB 1, certain program and budgetary details set forth in D.06-01-024 and D.06-08-028 required modification, which the Commission modified in D.06-12-033. D.06-12-033 also modified D.06-01-024 to clarify that, although solar projects may be sized up to five MW under that decision, an individual project may receive incentives only up to the first MW as SB 1 mandates, commencing with applications for solar incentives after January 1, 2007.

3. Current Status of the CSI Program

In January 2007, the CPUC launched the CSI Program with a budget of $2.16 billion for the years 2007-2016, including 1,750 MW in the mainstream incentive program.[39] The 1,750 MW are divided by Program Administrator and by customer class (residential and non-residential) (commercial and government/non-profit).[40] SCE has 46% of the MW goals of the program. Thus, SCE's CSI target is 805 MW, divided into 265.6 MW for residential customers and 539.5 MW for non-residential customers. For the first year of CSI, SCE has applications for 7.3 MW of solar PV power for residential customers and 74.8 MW for non-residential customers.[41] Residential applications total 1,381 (18% of the total of 7,541) and non-residential applications total 211 (3% of the total) for commercial customers and 48 (1% of the total) for government and non-profit customers.[42]

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[39] CSI Staff Progress Report, January 2008, p. 4.

[40] CSI Staff Progress Report, January 2008, p. 7.

[41] Non-residential includes 63.8 MW for commercial customers and 11.0 MW for government/non-profit customers. CSI Staff Progress Report, January 2008, p. 18. Table 4.

[42] Id.

CERTIFICATE OF SERVICE

I hereby certify that, pursuant to the Commission's Rules of Practice and Procedure, I have this day served a true copy of APPLICATION OF SOUTHERN CALIFORNIA EDISON COMPANY (U 338-E) FOR AUTHORITY TO IMPLEMENT AND RECOVER IN RATES THE COST OF ITS PROPOSED SOLAR PHOTOVOLTAIC (PV) PROGRAM on all parties identified on the attached service list(s). Service was effected by one or more means indicated below:

Transmitting the copies via e-mail to all parties who have provided an e-mail address. First class mail will be used if electronic service cannot be effectuated.

Executed this 27th day of March 2008, at Rosemead, California.

/s/ Melissa Schary
Melissa Schary
Case Analyst
SOUTHERN CALIFORNIA EDISON COMPANY

2244 Walnut Grove Avenue
Post Office Box 800
Rosemead, California 91770

CASE ADMINISTRATION
SOUTHERN CALIFORNIA EDISON COMPANY
2244 WALNUT GROVE AVE.
ROSEMEAD, CA 91770
A.07-11-011

Bernard Ayanruoh
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 4205
SAN FRANCISCO, CA 94102-3214
A.07-11-011

ROCHELLE BECKER
ALLIANCE FOR NUCLEAR RESPONSIBILITY
PO BOX 1328
SAN LUIS OBISPO, CA 93406
A.07-11-011

KATHLEEN M. BELLOMO
ATTORNEY AT LAW
KATHLEEN MALONEY BELLOMO
BOX 217, E. MONO LAKE DRIVE
LEE VINING, CA 93541
A.07-11-011

ANDREW B. BROWN
ATTORNEY AT LAW
ELLISON, SCHNEIDER & HARRIS, LLP
2015 H STREET
SACRAMENTO, CA 95811
A.07-11-011

DAVID J. BYERS
MCCRACKEN & BYERS, LLP
1920 LESLIE STREET
SAN MATEO, CA 94403
A.07-11-011

RONALD M. CERNIGLIA
DIRECTOR- NATIONAL ADVOCACY
DIRECT ENERGY SERVICES, LLC
40 COLUMBINE DRIVE
GLENMONT, NY 12077-2966
A.07-11-011

Taaru Chawla
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 4209
SAN FRANCISCO, CA 94102-3214
A.07-11-011

HILARY CORRIGAN
CALIFORNIA ENERGY MARKETS
425 DIVISADERO ST., SUITE 303
SAN FRANCISCO, CA 94117
A.07-11-011

REGINA COSTA
THE UTILITY REFORM NETWORK
711 VAN NESS AVENUE, SUITE 350
SAN FRANCISCO, CA 94102
A.07-11-011

BRIAN T. CRAGG
ATTORNEY AT LAW
GOODIN, MACBRIDE, SQUERI, RITCHIE & DAY
505 SANSOME STREET, SUITE 900
SAN FRANCISCO, CA 94111
A.07-11-011

MICHAEL B. DAY
ATTORNEY AT LAW
GOODIN MACBRIDE SQUERI DAY & LAMPREY LLP
505 SANSOME STREET, SUITE 900
SAN FRANCISCO, CA 94111
A.07-11-011

Matthew Deal
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 5215
SAN FRANCISCO, CA 94102-3214
A.07-11-011

Regina DeAngelis
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 5022
SAN FRANCISCO, CA 94102-3214
A.07-11-011

DANIEL W. DOUGLASS
ATTORNEY AT LAW
DOUGLASS & LIDDELL
21700 OXNARD STREET, SUITE 1030
WOODLAND HILLS, CA 91367-8102
A.07-11-011

ELIZABETH DOUGLASS
STAFF WRITER
LOS ANGELES TIMES
202 WEST FIRST STREET
LOS ANGELES, CA 90012
A.07-11-011

Marshal B. Enderby
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 4205
SAN FRANCISCO, CA 94102-3214
A.07-11-011

ROBERT FINKELSTEIN
ATTORNEY AT LAW
THE UTILITY REFORM NETWORK
711 VAN NESS AVE., SUITE 350
SAN FRANCISCO, CA 94102
A.07-11-011

BRUCE FOSTER, SR.
SENIOR VICE PRESIDENT
SOUTHERN CALIFORNIA EDISON COMPANY
601 VAN NESS AVENUE., STE. 2040
SAN FRANCISCO, CA 94102
A.07-11-011

ROBERT GNAIZDA
POLICY DIRECTOR/GENERAL COUNSEL
THE GREENLINING INSTITUTE
1918 UNIVERSITY AVENUE, SECOND FLOOR
BERKELEY, CA 94704
A.07-11-011

PATRICK G. GOLDEN
ATTORNEY AT LAW
PACIFIC GAS AND ELECTRIC COMPANY
77 BEALE STREET, MAIL CODE B30A
SAN FRANCISCO, CA 94105
A.07-11-011

THALIA N.C. GONZALEZ
ATTORNEY AT LAW
THE GREENLINING INSTITUTE
1918 UNIVERSITY AVENUE, 2ND FLOOR
BERKELEY, CA 94704
A.07-11-011

HAYLEY GOODSON
ATTORNEY AT LAW
THE UTILITY REFORM NETWORK
711 VAN NESS AVENUE, SUITE 350
SAN FRANCISCO, CA 94102
A.07-11-011

Eric Greene
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
AREA 4-A
SAN FRANCISCO, CA 94102-3214
A.07-11-011

TANYA A. GULESSERIAN
ATTORNEY AT LAW
ADAMS BROADWELL JOSEPH & CARDOZO
601 GATEWAY BLVD. STE 1000
SOUTH SAN FRANCISCO, CA 94080
A.07-11-011

RICIA R. HAGER
ATTORNEY AT LAW
WOODRUFF, SPRADLIN & SMART
555 ANTON BOULEVARD, SUITE 1200
COSTA MESA, CA 92626-7670
A.07-11-011

JENNIFER HASBROUCK
ATTORNEY AT LAW
SOUTHERN CALIFORNIA EDISON COMPANY
2244 WALNUT GROVE AVENUE PO BOX 800
ROSEMEAD, CA 91770
A.07-11-011

ROGER HELLER
ATTORNEY AT LAW
DISABILITY RIGHTS ADVOCATES
2001 CENTER STREET, THIRD FLOOR
BERKELEY, CA 94704
A.07-11-011

DAVID L.. HUARD
ATTORNEY AT LAW
MANATT PHELPS & PHILLIPS LLP
11355 WEST OLYMPIC BOULEVARD
LOS ANGELES, CA 90064
A.07-11-011

MARC D. JOSEPH
ATTORNEY AT LAW
ADAMS, BROADWELL, JOSEPH & CARDOZO
601 GATEWAY BLVD., STE. 1000
SOUTH SAN FRANCISCO, CA 94080
A.07-11-011

STEVEN KELLY
POLICY DIRECTOR
INDEPENDENT ENERGY PRODUCERS ASSN
1215 K STREET, SUITE 900
SACRAMENTO, CA 95814
A.07-11-011

PAUL KERKORIAN
UTILITY COST MANAGEMENT, LLC
6475 N. PALM AVENUE, SUITE 105
FRESNO, CA 93704
A.07-11-011

GREGORY S. G. KLATT
ATTORNEY AT LAW
DOUGLASS & LIDDELL
411 E. HUNTINGTON DRIVE, SUITE 107-356
ARCADIA, CA 91007
A.07-11-011

Donald J. Lafrenz
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
AREA 4-A
SAN FRANCISCO, CA 94102-3214
A.07-11-011

DON LIDDELL
ATTORNEY AT LAW
DOUGLASS & LIDDELL
2928 2ND AVENUE
SAN DIEGO, CA 92103
A.07-11-011

RONALD LIEBERT
ATTORNEY AT LAW
CALIFORNIA FARM BUREAU FEDERATION
2300 RIVER PLAZA DRIVE
SACRAMENTO, CA 95833
A.07-11-011

KAREN A. LINDH
LINDH & ASSOCIATES
7909 WALERGA ROAD, NO. 112, PMB119
ANTELOPE, CA 95843
A.07-11-011

Martin G. Lyons
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 4205
SAN FRANCISCO, CA 94102-3214
A.07-11-011

MARY LYNCH
VP - REGULATORY AND LEGISLATIVE AFFAIRS
CONSTELLATION ENERGY COMMODITIES GROUP
2377 GOLD MEDAL WAY, SUITE 100
GOLD RIVER, CA 95670
A.07-11-011

KENDALL H. MACVEY, ESQ.
ATTORNEY AT LAW
BEST, BEST & KRIEGER, LLP
3750 UNIVERSITY AVENUE, SUITE 300
RIVERSIDE, CA 92501
A.07-11-011

CAROL MANSON
SAN DIEGO GAS & ELECTRIC CO.
8330 CENTURY PARK COURT CP32D
SAN DIEGO, CA 92123
A.07-11-011

BILL MARCUS
JBS ENERGY, INC.
311 D STREET, SUITE A
WEST SACRAMENTO, CA 95605
A.07-11-011

DAVID MARCUS
PO BOX 1287
BERKELEY, CA 94701
A.07-11-011

RICHARD MCCANN
M.CUBED
2655 PORTAGE BAY, SUITE 3
DAVIS, CA 95616
A.07-11-011

KEITH R. MCCREA
ATTORNEY AT LAW
SUTHERLAND, ASBILL & BRENNAN, LLP
1275 PENNSYLVANIA AVE., N.W.
WASHINGTON, DC 20004-2415
A.07-11-011

FRANK A. MCNULTY
ATTORNEY AT LAW
SOUTHERN CA. EDISON CO.
2244 WALNUT GROVE AVE
ROSEMEAD, CA 91770
A.07-11-011

Ed Moldavsky
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 5125
SAN FRANCISCO, CA 94102-3214
A.07-11-011

EDWARD W. O'NEILL
ATTORNEY AT LAW
DAVIS WRIGHT TREMAINE LLP
505 MONTGOMERY STREET, SUITE 800
SAN FRANCISCO, CA 94111-6533
A.07-11-011

Robert M. Pocta
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 4205
SAN FRANCISCO, CA 94102-3214
A.07-11-011

JOHNNY PONG
SEMPRA ENERGY
555 WEST FIFTH STREET NO. 1400
LOS ANGELES, CA 90013-1011
A.07-11-011

EDWARD G. POOLE
ATTORNEY AT LAW
ANDERSON, DONOVAN & POOLE
601 CALIFORNIA STREET, SUITE 1300
SAN FRANCISCO, CA 94108-2818
A.07-11-011

JESSE W. RASKIN
LEGAL ASSOCIATE
THE GREENLINING INSTITUTE
1918 UNIVERSITY AVENUE, 2ND FLOOR
BERKELEY, CA 94704
A.07-11-011

Lisa-Marie Salvacion
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 4107
SAN FRANCISCO, CA 94102-3214
A.07-11-011

Andrew Schwartz
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 5217
SAN FRANCISCO, CA 94102-3214
A.07-11-011

REED V. SCHMIDT
BARTLE WELLS ASSOCIATES
1889 ALCATRAZ AVENUE
BERKELEY, CA 94703-2714
A.07-11-011

MICHAEL SHAMES
ATTORNEY AT LAW
UTILITY CONSUMERS' ACTION NETWORK
3100 FIFTH AVENUE, SUITE B
SAN DIEGO, CA 92103
A.07-11-011

NORA SHERIFF
ATTORNEY AT LAW
ALCANTAR & KAHL, LLP
120 MONTGOMERY STREET, SUITE 2200
SAN FRANCISCO, CA 94104
A.07-11-011

JAMES D. SQUERI
ATTORNEY AT LAW
GOODIN MACBRIDE SQUERI DAY & LAMPREY
505 SANSOME STREET, SUITE 900
SAN FRANCISCO, CA 94111
A.07-11-011

Laura Lei Strain
CALIF PUBLIC UTILITIES COMMISSION
320 WEST 4TH STREET SUITE 500
LOS ANGELES, CA 90013
A.07-11-011

ANDREW STEINBERG
SAN DIEGO GAS & ELECTRIC/SOCALGAS
555 W. FIFTH STREET, GT14D6
LOS ANGELES, CA 90013
A.07-11-011

NINA SUETAKE
ATTORNEY AT LAW
THE UTILITY REFORM NETWORK
711 VAN NESS AVE., STE 350
SAN FRANCISCO, CA 94102
A.07-11-011

KAREN TERRANOVA
ALCANTAR & KAHL, LLP
120 MONTGOMERY STREET, STE 2200
SAN FRANCISCO, CA 94104
A.07-11-011

Laura J. Tudisco
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 5032
SAN FRANCISCO, CA 94102-3214
A.07-11-011

JAMES F. WALSH
ATTORNEY AT LAW
SEMPRA ENERGY
101 ASH STREET
SAN DIEGO, CA 92101-3017
A.07-11-011

JAMES WEIL
DIRECTOR
AGLET CONSUMER ALLIANCE
PO BOX 37
COOL, CA 95614
A.07-11-011

RUSSELL G. WORDEN
SOUTHERN CALIFORNIA EDISON COMPANY
2244 WALNUT GROVE AVENUE
ROSEMEAD, CA 91770
A.07-11-011

MRW & ASSOCIATES, INC.
1814 FRANKLIN STREET, SUITE 720
OAKLAND, CA 94612
A.07-11-011

CASE ADMINISTRATION
SOUTHERN CALIFORNIA EDISON COMPANY
2244 WALNUT GROVE AVENUE
ROSEMEAD, CA 91770
R.08-02-007

STACY AGUAYO
APS ENERGY SERVICES COMPANY, INC.
400 E. VAN BUREN STREET, SUITE 750
PHOENIX, AZ 85004
R.08-02-007

MICHAEL ALCANTAR
ATTORNEY AT LAW
ALCANTAR & KAHL LLP
1300 SW FIFTH AVENUE, SUITE 1750
PORTLAND, OR 97201
R.08-02-007

FRANK ANNUNZIATO
PRESIDENT
AMERICAN UTILITY NETWORK INC.
10705 DEER CANYON DR.
ALTA LOMA, CA 91737-2483
R.08-02-007

ROD AOKI
ATTORNEY AT LAW
ALCANTAR & KAHL, LLP
120 MONTGOMERY STREET, SUITE 2200
SAN FRANCISCO, CA 94104
R.08-02-007

GALEN BARBOSE
LAWRENCE BERKELEY NATIONAL LAB
1 CYCLOTRON RD.
MS 90-4000
BERKELEY, CA 94720
R.08-02-007

BARBARA R. BARKOVICH
BARKOVICH & YAP, INC.
44810 ROSEWOOD TERRACE
MENDOCINO, CA 95460
R.08-02-007

THOMAS BLAIR
CITY OF SAN DIEGO
9601 RIDGEHAVEN COURT, STE. 120/MS11
SAN DIEGO, CA 92123
R.08-02-007

SCOTT BLAISING
ATTORNEY AT LAW
BRAUN & BLAISING, P.C.
915 L STREET, STE. 1270
SACRAMENTO, CA 95814
R.08-02-007

KEVIN BOUDREAUX
CALPINE POWER AMERICA-CA LLC
4160 DUBLIN BLVD
DUBLIN, CA 94568
R.08-02-007

MICHAEL E. BOYD
CALIFORNIANS FOR RENEWABLE ENERGY, INC.
5439 SOQUEL DRIVE
SOQUEL, CA 95073
R.08-02-007

Carol A Brown
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 5103
SAN FRANCISCO, CA 94102-3214
R.08-02-007

DAVID BRANCHCOMB
BRANCHCOMB ASSOCIATES, LLC
9360 OAKTREE LANE
ORANGEVILLE, CA 95662
R.08-02-007

LYNNE M. BROWN
CALIFORNIANS FOR RENEWABLE ENERGY INC.
24 HARBOR ROAD
SAN FRANCISCO, CA 94124
R.08-02-007

MICHAEL CARANO
RATE REGULATORY RELATIONS
ANZA ELECTRIC COOPERATIVE, INC
PO BOX 10100 6100 NEAL ROAD
RENO, NV 89520-0026
R.08-02-007

BILL CHEN
CONSTELLATION NEW ENERGY, INC.
SOUTH GRAND AVENUE, SUITE 3800
LOS ANGELES, CA 90071
R.08-02-007

BRIAN K. CHERRY
VICE PRESIDENT, REGULATORY RELATIONS
PACIFIC GAS AND ELECTRIC COMPANY
PO BOX 770000, MAIL CODE: B10C
SAN FRANCISCO, CA 94177
R.08-02-007

KRIS G. CHISHOLM
STAFF COUNSEL
CALIFORNIA ELECTRICITY OVERSIGHT BOARD
770 L STREET, SUITE 1250
SACRAMENTO, CA 95831
R.08-02-007

BRIAN T. CRAGG
ATTORNEY AT LAW
GOODIN, MACBRIDE, SQUERI, RITCHIE & DAY
505 SANSOME STREET, SUITE 900
SAN FRANCISCO, CA 94111
R.08-02-007

THOMAS DARTON
PILOT POWER GROUP, INC.
9320 CHESAPEAKE DRIVE, SUITE 112
SAN DIEGO, CA 92123
R.08-02-007

BALDASSARO DI CAPO, ESQ.
CALIFORNIA ISO
151 BLUE RAVINE ROAD
FOLSOM, CA 95630
R.08-02-007

JEFF DIAMOND
CALIFORNIA ELECTRICITY OVERSIGHT BOARD
770 L STREET, SUITE 1250
SACRAMENTO, CA 95814
R.08-02-007

CHI DOAN
CALIFORNIA DEPARTMENT OF WATER RESOURCES
3310 EL CAMINO AVE., ROOM LL94
SACRAMENTO, CA 95821
R.08-02-007

MICHAEL DOUGHTON
CALIFORNIA ENERGY COMMISSION
1516 9TH STREET MS-14
SACRAMENTO, CA 95814
R.08-02-007

DANIEL W. DOUGLASS
ATTORNEY AT LAW
DOUGLASS & LIDDELL
21700 OXNARD STREET, SUITE 1030
WOODLAND HILLS, CA 91367
R.08-02-007

KEVIN DUGGAN
DIR OF WESTERN REG. AFFAIRS.
CALPINE COPRORATION
3875 HOPYARD ROAD, SUITE 345
PLEASANTON, CA 94588
R.08-02-007

PIERRE H. DUVAIR, PH.D
CALIFORNIA ENERGY COMISSION
1516 NINTH STREET
SACRAMENTO, CA 95814
R.08-02-007

JULIE L. FIEBER
FOLGER LEVIN & KAHN LLP
275 BATTERY STREET, 23RD FLOOR
SAN FRANCISCO, CA 94111
R.08-02-007

MICHEL PETER FLORIO
ATTORNEY AT LAW
THE UTILITY REFORM NETWORK (TURN)
711 VAN NESS AVENUE, SUITE 350
SAN FRANCISCO, CA 94102
R.08-02-007

ROBERT B. GEX
ATTORNEY AT LAW,
DAVIS WRIGHT TREMAINE LLP
505 MONTGOMERY STREET, SUITE 800
SAN FRANCISCO, CA 94111-6533
R.08-02-007

INGER GOODMAN
COMMERCE ENERGY, INC.
600 ANTON BLVD., SUITE 2000
COSTA MESA, CA 92626
R.08-02-007

JEFFREY GRAY
ATTORNEY AT LAW
DAVIS WRIGHT TREMAINE
505 MONTGOMERY STREET, SUITE 800
SAN FRANCISCO, CA 94111-6533
R.08-02-007

JOSEPH GRECO
TERRA-GEN POWER, LLC
9590 PROTOTYPE COURT, SUITE 200
RENO, NV 89521
R.08-02-007

KAREN GRIFFIN
EXECUTIVE OFFICE
CALIFORNIA ENERGY COMMISSION
1516 9TH STREET, MS 39
SACRAMENTO, CA 95814
R.08-02-007

GEORGE HANSON
DEPARTMENT OF WATER AND POWER
CITY OF CORONA
730 CORPORATION YARD WAY
CORONA, CA 92880
R.08-02-007

AUDRA HARTMANN
DYNEGY, INC.
980 NINTH STREET, SUITE 2130
SACRAMENTO, CA 95814
R.08-02-007

ANN HENDRICKSON
COMMERCE ENERGY, INC.
222 WEST LAS COLINAS BLVD., SUITE 950E
IRVING, TX 75039
R.08-02-007

CARYN HOLMES
CALIFORNIA ENERGY COMMISSION
1516 9TH STREET, MS-14
SACRAMENTO, CA 95814
R.08-02-007

MARTIN HOMEC
ATTORNEY AT LAW
LAW OFFICE OF MARTIN HOMEC
PO BOX 4471
DAVIS, CA 95617
R.08-02-007

KERRY HUGHES
STRATEGIC ENERGY, LTD
7220 AVENIDA ENCINAS, SUITE 120
CARLSBAD, CA 92209
R.08-02-007

TAM HUNT
ENERGY PROGRAM DIRECTOR/ATTORNEY
COMMUNITY ENVIRONMENTAL COUNCIL
26 W. ANAPAMU, 2ND FLOOR
SANTA BARBARA, CA 93101
R.08-02-007

MIKE JASKE
CALIFORNIA ENERGY COMMISSION
1516 NINTH STREET, MS-22
SACRAMENTO, CA 95814
R.08-02-007

AKBAR JAZAYEIRI
DIR. REVENUE & TARIFFS, RM 390
SOUTHERN CALIFORNIA EDISON COMPANY
PO BOX 800
ROSEMEAD, CA 91770
R.08-02-007

MARC D. JOSEPH
ATTORNEY AT LAW
ADAMS, BROADWELL, JOSEPH & CARDOZO
601 GATEWAY BLVD., STE. 1000
SOUTH SAN FRANCISCO, CA 94080
R.08-02-007

EVELYN KAHL
ATTORNEY AT LAW
ALCANTAR & KAHL, LLP
120 MONTGOMERY STREET, SUITE 2200
SAN FRANCISCO, CA 94104
R.08-02-007

STEVEN KELLY
POLICY DIRECTOR
INDEPENDENT ENERGY PRODUCERS ASSN
1215 K STREET, SUITE 900
SACRAMENTO, CA 95814
R.08-02-007

KEVIN KENNEDY
SUPERVISOR, SPECIAL PROJECTS
CALIFORNIA ENERGY COMMISSION
1516 9TH STREET, MS-48
SACRAMENTO, CA 95814
R.08-02-007

Sepideh Khosrowjah
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 4101
SAN FRANCISCO, CA 94102-3214
R.08-02-007

GREGORY S. G. KLATT
ATTORNEY AT LAW
DOUGLASS & LIDDELL
411 E. HUNTINGTON DRIVE, SUITE 107-356
ARCADIA, CA 91007
R.08-02-007

DAVID X. KOLK, PH.D.
COMPLETE ENERGY SERVICE, INC.
41422 MAGNOLIA STREET
MURRIETA, CA 92562
R.08-02-007

JOHN KOTOWSKI
GLOBAL ENERGY PARTNERS, LLC
3569 MT. DIABLO BLVD., STE 200
LAFAYETTE, CA 94549
R.08-02-007

AVIS KOWALEWSKI
CALPINE CORPORATION
3875 HOPYARD ROAD, SUITE 345
PLEASANTON, CA 94588
R.08-02-007

DOUGLAS LARSON
PACIFICORP
201 SOUTH MAIN
SALT LAKE CITY, UT 84111
R.08-02-007

CLARE LAUFENBERG
CALIFORNIA ENERGY COMMISSION
1516 NINTH STREET, MS 46
SACRAMENTO, CA 95814
R.08-02-007

VITALY LEE
AES ALAMITOS, LLC
690 N. STUDEBAKER ROAD
LONG BEACH, CA 90803
R.08-02-007

CONTANCE LENI
CALIFORNIA ENERGY COMMISSION
1516 NINTH ST., MS-20
SACRAMENTO, CA 95814
R.08-02-007

JOHN W. LESLIE, ESQ.
ATTORNEY AT LAW
LUCE, FORWARD, HAMILTON & SCRIPPS, LLP
11988 EL CAMINO REAL, SUITE 200
SAN DIEGO, CA 92130
R.08-02-007

GUSTAVO LUNA
AES CORPORATION
690 N. STUDEBAKER RD.
LONG BEACH, CA 90803
R.08-02-007

LYNELLE LUND
COMMERCE ENERGY, INC.
600 ANTON BLVD., SUITE 2000
COSTA MESA, CA 92626
R.08-02-007

MARY LYNCH
VP - REGULATORY AND LEGISLATIVE AFFAIRS
CONSTELLATION ENERGY COMMODITIES GROUP
2377 GOLD MEDAL WAY, SUITE 100
GOLD RIVER, CA 95670
R.08-02-007

MEGAN MAO
SOUTHERN CALIFORNIA EDISON COMPANY
2244 WALNUT GROVE AVE
ROSEMEAD, CA 91770
R.08-02-007

ROBERT MARSHALL
PLUMAS SIERRA RURAL ELECTRIC COOP.
PO BOX 2000
PORTOLA, CA 96122-2000
R.08-02-007

PAUL D. MAXWELL
NAVIGANT CONSULTING, INC.
3100 ZINFANDEL DRIVE, SUITE 600
RANCHO CORDOVA, CA 95670-6078
R.08-02-007

MICHAEL MAZUR
3 PHASES RENEWABLES, LLC
2100 SEPULVEDA BLVD, STE. 37
MANHATTAN BEACH, CA 90266
R.08-02-007

TRINA MCALISTER
FOLGER LEVIN & KAHN LLP
275 BATTERY STREET, 23RD FLOOR
SAN FRANCISCO, CA 94111
R.08-02-007

RICHARD MCCANN
M.CUBED
2655 PORTAGE BAY, SUITE 3
DAVIS, CA 95616
R.08-02-007

BRUCE MCLAUGHLIN
ATTORNEY AT LAW
BRAUN & BLAISING P.C.
915 L STREET SUITE 1420
SACRAMENTO, CA 95814
R.08-02-007

RACHEL MCMAHON
CEERT
1100 11TH STREET, SUITE 311
SACRAMENTO, CA 95814
R.08-02-007

CHARLES R. MIDDLEKAUF
PACIFIC GAS AND ELECTRIC COMPANY
PO BOX 7742
SAN FRANCISCO, CA 94120
R.08-02-007

ROSS MILLER
CALIFORNIA ENERGY COMMISSION
1516 9TH STREET
SACRAMENTO, CA 95814
R.08-02-007

KAREN MILLS
CALIFORNIA FARM BUREAU FEDERATION
2300 RIVER PLAZA DRIVE
SACRAMENTO, CA 95833
R.08-02-007

MARCIE MILNER
CORAL ENERGY RESOURCES, L P
4445 EASTGATE MALL, SUITE 100
SAN DIEGO, CA 92121
R.08-02-007

RONALD MOORE
SOUTHERN CALIFORNIA WATER COMPANY
630 EAST FOOTHILL BLVD.
SAN DIMAS, CA 91773
R.08-02-007

STEPHEN A. S. MORRISON
CITY & COUNTY OF SAN FRANCISCO
1 DR CARLTON B. GOODLETT PLACE
SAN FRANCISCO, CA 94102-4682
R.08-02-007

GREGORY MORRIS
GREEN POWER INSTITUTE
2039 SHATTUCK AVE., SUITE 402
BERKELEY, CA 94704
R.08-02-007

ROBERT NICHOLS
NEW WEST ENERGY
PO BOX 61868 MAILING STATION ISB 665
PHOENIX, AZ 85082-1868
R.08-02-007

SEPHRA A. NINOW
POLICY ANALYST
CALIFORNIA CENTER FOR SUSTAINABLE ENERGY
8690 BALBOA AVENUE, SUITE 100
SAN DIEGO, CA 92123
R.08-02-007

RICK C. NOGER
PRAXAIR PLAINFIELD, INC.
2711 CENTERVILLE ROAD, SUITE 400
WILMINGTON, DE 19808
R.08-02-007

EDWARD O'NEILL
ATTORNEY AT LAW
DAVIS WRIGHT TREMAINE
505 MONTGOMERY STREET, SUITE 800
SAN FRANCISCO, CA 94111-6533
R.08-02-007

Noel Obiora
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 4107
SAN FRANCISCO, CA 94102-3214
R.08-02-007

CHIEF OPERATING OFFICER
MOUNTAIN UTILITIES
PO BOX 205
KIRKWOOD, CA 95646
R.08-02-007

DAVID ORTH
GENERAL MANAGER
SAN JOAQUIN VALLEY POWER AUTHORITY
4886 EAST JENSEN AVENUE
FRESNO, CA 93725
R.08-02-007

FRITZ ORTLIEB
ATTORNEY AT LAW
CITY OF SAN DIEGO
1200 THIRD AVENUE, SUITE 1200
SAN DIEGO, CA 92101
R.08-02-007

Karen P Paull
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
ROOM 4300
SAN FRANCISCO, CA 94102-3214
R.08-02-007

JOHN A. PACHECO
ATTORNEY AT LAW
SEMPRA ENERGY
101 ASH STREET, HQ-12
SAN DIEGO, CA 92101-3017
R.08-02-007

BERJ K. PARSEGHIAN
SOUTHERN CALIFORNIA EDISON COMPANY
2244 WALNUT GROVE AVENUE
ROSEMEAD, CA 91770
R.08-02-007

EDWARD G. POOLE
ATTORNEY AT LAW
ANDERSON & POOLE
601 CALIFORNIA STREET, SUITE 1300
SAN FRANCISCO, CA 94108-2818
R.08-02-007

TED POPE
DIRECTOR
COHEN VENTURES, INC./ENERGY SOLUTIONS
1738 EXCELSIOR AVENUE
OAKLAND, CA 94602
R.08-02-007

JENNIFER PORTER
POLICY ANALYST
CALIFORNIA CENTER FOR SUSTAINABLE ENERGY
8690 BALBOA AVENUE, SUITE 100
SAN DIEGO, CA 92123
R.08-02-007

MARC PRYOR
CALIFORNIA ENERGY COMMISSION
1516 9TH ST, MS 20
SACRAMENTO, CA 95814
R.08-02-007

ADRIAN PYE
ENERGY AMERICA, LLC
263 TRESSER BLVD, ONE STAMFORD PLZ
8TH F
STAMFORD, CT 6901
R.08-02-007

NANCY RADER
CALIFORNIA WIND ENERGY ASSOCIATION
2560 NINTH STREET, SUITE 213A
BERKELEY, CA 94710
R.08-02-007

STEVE RAHON
DIRECTOR, TARIFF & REG. ACCOUNTS
SAN DIEGO GAS & ELECTRIC COMPANY
8330 CENTURY PARK COURT, CP32C
SAN DIEGO, CA 92123-1548
R.08-02-007

JOHN R. REDDING
ARCTURUS ENERGY CONSULTING, INC.
44810 ROSEWOOD TERRACE
MENDOCINO, CA 95460-9525
R.08-02-007

L. JAN REID
COAST ECONOMIC CONSULTING
3185 GROSS ROAD
SANTA CRUZ, CA 95062
R.08-02-007

MIKE RINGER
CALIFORNIA ENERGY COMMISSION
1516 NINTH STREET, MS-20
SACRAMENTO, CA 95814
R.08-02-007

GRANT A. ROSENBLUM
SENIOR COUNSEL
CALIFORNIA INDEPENDENT SYSTEM
OPERATOR
151 BLUE RAVINE ROAD
FOLSOM, CA 95630
R.08-02-007

Jason R. Salmi Klotz
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
AREA 4-A
SAN FRANCISCO, CA 94102-3214
R.08-02-007

JUDITH B. SANDERS
ATTORNEY AT LAW
CALIFORNIA INDEPENDENT SYSTEM
OPERATOR
151 BLUE RAVINE ROAD
FOLSOM, CA 95630
R.08-02-007

MEGAN SAUNDERS
SEMPRA ENERGY SOLUTIONS
101 ASH STREET, HQ09
SAN DIEGO, CA 92101-3017
R.08-02-007

STEVEN S. SCHLEIMER
DIRECTOR,COMPLIANCE & REGULATORY
AFFAIRS
BARCLAYS BANK, PLC
200 PARK AVENUE, FIFTH FLOOR
NEW YORK, NY 10166
R.08-02-007

REED V. SCHMIDT
BARTLE WELLS ASSOCIATES
1889 ALCATRAZ AVENUE
BERKELEY, CA 94703-2714
R.08-02-007

Melissa Semcer
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
AREA 4-A
SAN FRANCISCO, CA 94102-3214
R.08-02-007

LILI SHAHRIARI
AOL UTILITY CORP
12752 BARRETT LANE
SANTA ANA, CA 92705
R.08-02-007

NORA SHERIFF
ATTORNEY AT LAW
ALCANTAR & KAHL, LLP
120 MONTGOMERY STREET, SUITE 2200
SAN FRANCISCO, CA 94104
R.08-02-007

DAN SILVERIA
SURPRISE VALLEY ELECTRIC
CORPORATION
PO BOX 691
ALTURAS, CA 96101
R.08-02-007

SEEMA SRINIVASAN
ATTORNEY AT LAW
ALCANTAR & KAHL, LLP
120 MONTGOMERY STREET, SUITE 2200
SAN FRANCISCO, CA 94104
R.08-02-007

Elizabeth Stoltzfus
CALIF PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
AREA 4-A
SAN FRANCISCO, CA 94102-3214
R.08-02-007

BOB TANG
ASSISTANT DIRECTOR
CITY OF AZUSA
729 NORTH AZUSA AVENUE
AZUSA, CA 91702-9500
R.08-02-007

KAREN TERRANOVA
ALCANTAR & KAHL, LLP
120 MONTGOMERY STREET, STE 2200
SAN FRANCISCO, CA 94104
R.08-02-007

BRIAN THEAKER
DYNEGY
980 NINTH STREET, SUITE 2130
SACRAMENTO, CA 95814
R.08-02-007

NANCY TRONAAS
CALIFORNIA ENERGY COMMISSION
1516 9TH ST. MS-20
SACRAMENTO, CA 95814-5512
R.08-02-007

BETH VAUGHAN
CALIFORNIA COGENERATION COUNCIL
4391 N. MARSH ELDER COURT
CONCORD, CA 94521
R.08-02-007

DAVID VIDAVER
CALIFORNIA ENERGY COMMISSION
1516 NINTH STREET, MS-20
SACRAMENTO, CA 95814
R.08-02-007

COURTNEY WEDDINGTON
COMPLIANCE ANALYST
COMMERCE ENERGY INC
222 W. LAS COLINAS BLVD., STE. 950-E
IRVING, TX 75039
R.08-02-007

JAMES WEIL
DIRECTOR
AGLET CONSUMER ALLIANCE
PO BOX 37
COOL, CA 95614
R.08-02-007

DEANA M. WHITE
ATTORNEY AT LAW
SOUTHERN CALIFORNIA EDISON COMPANY
2244 WALNUT GROVE AVENUE
ROSEMEAD, CA 91770
R.08-02-007

RYAN WISER
BERKELEY LAB
ONE CYCLOTRON ROAD
MS-90-4000
BERKELEY, CA 94720
R.08-02-007

ALEXIS K. WODTKE
STAFF ATTORNEY
CONSUMER FEDERATION OF CALIFORNIA
520 S. EL CAMINO REAL, STE. 340
SAN MATEO, CA 94402
R.08-02-007

LANA WONG
CALIFORNIA ENERGY COMMISSION
1516 NINTH ST., MS-20
SACRAMENTO, CA 95814
R.08-02-007

JIM WOODWARD
CALIFORNIA ENERGY COMMISSION
1516 NINTH STREET, MS 20
SACRAMENTO, CA 95814-5504
R.08-02-007

E. J. WRIGHT
OCCIDENTAL POWER SERVICES, INC.
5 GREENWAY PLAZA, SUITE 110
HOUSTON, TX 77046
R.08-02-007

MRW & ASSOCIATES, INC.
1814 FRANKLIN STREET, SUITE 720
OAKLAND, CA 94612
R.08-02-007

CALIFORNIA ENERGY MARKETS
517-B POTRERO AVENUE
SAN FRANCISCO, CA 94110
R.08-02-007

LEGAL AND REGULATORY DEPARTMENT
CALIFORNIA ISO
151 BLUE RAVINE ROAD
FOLSOM, CA 95630
R.08-02-007

California Public Utilities Commission
505 Van Ness Ave., San Francisco

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Media Contact: Terrie Prosper, 415.703.1366, news@cpuc.ca.gov Docket #: A. 09-02-019

CPUC APPROVES SOLAR PV PROGRAM FOR PG&E

SAN FRANCISCO, April 22, 2010 - The California Public Utilities Commission (CPUC) today authorized a five-year solar photovoltaic (PV) program to develop up to 500 megawatts (MW) of solar PV facilities in the range of 1 to 20 MW in Pacific Gas and Electric Company's (PG&E) service area.

The PV program allows for development of solar facilities owned by PG&E and also owned by third parties. Under the utility owned portion of the PV program, PG&E is authorized to install up to 250 MW of PV facilities from 1 to 20 MW in size in its service area at a rate of 50 MW per year. Similarly, under the third-party owned portion of the program, PG&E can solicit energy from 250 MW of PV facilities from 1 to 20 MW in size located in its service area, also at a rate of 50 MW a year.

"This solar development program has many benefits and can help the state meet its aggressive renewable power goals," said CPUC President Michael R. Peevey. "Smaller scale projects can avoid many of the pitfalls that have plagued larger renewable projects in California, including permitting and transmission challenges. Because of this, programs targeting these resources can serve as a valuable complement to the existing Renewables Portfolio Standard program."

The CPUC authorized expenditures of up to $1.454 billion for the capital costs associated with the utility owned portion of the PV program. If PG&E develops fewer than 250 MW over the five year duration of the PV program, this amount will be adjusted based on the number of megawatts PG&E does develop. Pricing under the third-party owned PV will be based on competitive solicitations, with the successful bidders entering into a 20-year power purchase agreement with PG&E. Similarly, for utility owned projects, PG&E will conduct competitive solicitations for turn-key and

engineering, procurement and construction projects that the utility will then own and operate. To ensure the best price possible for ratepayers for projects developed by PG&E and those developed by independent power producers, PG&E must enlist the services of an independent evaluator to assess the fairness and robustness of its solicitations. Additionally, today's decision authorizes PG&E to recover the costs of a 2 MW pilot project the utility built to demonstrate the viability of this program. This facility is online and operating in Vacaville, California.

The proposal voted on today is available at:
http://docs.cpuc.ca.gov/PUBLISHED/AGENDA_DECISION/116784.htm.

For more information on the CPUC, please visit www.cpuc.ca.gov.

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BEFORE THE PUBLIC UTILITIES COMMISSION OF THE STATE OF CALIFORNIA

Order Instituting Rulemaking to Continue Implementation and Administration of California Renewables Portfolio Standard Program.	Rulemaking 08-08-009 (Filed August 21, 2008)

ADMINISTRATIVE LAW JUDGE'S RULING ON ADDITIONAL COMMISSION CONSIDERATION OF A FEED-IN TARIFF

This ruling files and serves a proposal by the Commission's Energy Division regarding key elements for a feed-in tariff. It also proposes taking official notice of the California Energy Commission 2008 Integrated Energy Policy Report Update. Respondents shall, and parties may, file and serve comments, reply comments and motions for hearing as provided herein. For the purpose of this ruling, respondents are Pacific Gas and Electric Company, Southern California Edison Company, and San Diego Gas & Electric Company.

1. Background

In compliance with Pub. Util. Code § 399.20, each electrical corporation has a tariff for the purchase of electricity generated from certain electrical facilities. These are facilities powered by renewable resources owned and operated by a public water or wastewater agency retail customer of the electric utility. The tariffs are for projects up to 1.5 megawatts (MW), and most tariffs also include a standard contract.[1] Three electrical corporations (Southern California Edison

[1] The tariffs of some electrical corporations are limited to projects up to 1.0 MW.

Company, Pacific Gas and Electric Company, and San Diego Gas & Electric Company) also have a tariff/standard contract for the purchase of electricity generated from certain electrical facilities powered by renewable resources that are owned and operated by other customers. These tariffs/standard contracts are also for projects up to 1.5 MW.[2]

By Amended Scoping Memo and Ruling dated June 5, 2008, the assigned Commissioner sought comments and reply comments on several topics. One topic was whether or not the project size eligible for the tariffs/standard contracts should be increased from 1.5 MW to 20 MW. Parties filed comments on July 4, 2008, and reply comments on July 14, 2008. Among the comments, some parties stated that additional terms and conditions might be needed if the eligible project size is increased from 1.5 MW to 20 MW.

On October 10, 2008, the Commission's Energy Division (ED) sought further data from parties. The information and comments were received on October 24, 2008. A second ED data request was issued on January 28, 2009, focusing specifically on contract terms and conditions. Data responses and comments were received on February 4, 2009. On February 10, 2009, ED held a workshop regarding standard terms and conditions for feed-in tariffs (FITs).

Topics addressed at the workshop included: categories for project size; location restrictions; insurance requirements; project development security; project assurance/delivery term security; performance obligation/energy delivery obligation; damage calculation/energy replacement damage amount; and guaranteed project milestones. In addition, several questions were framed

[2] See Decision (D.) 07-07-027, D.08-02-010, D.08-09-033; Resolution No. E-4137.

for discussion, including those within the following subject areas: project queue process; maximum permissible number of years for a project to come on-line; duplication, if any, in certain terms and conditions regarding security and milestones; and whether or not a standard contract among all utilities is desirable.

2. ED FIT Proposal, Comments, Replies, Motions

ED has prepared a recommendation for key elements of an FIT. (*See* Attachment A.) This proposal is based on ED's work with respondents and parties (*e.g.*, comments, reply comments, data responses, workshop).

Respondents shall, and parties may, file and serve comments and reply comments on the ED FIT Proposal. Comments and reply comments should also identify and discuss any other issue the party believes should be considered at this time. These pleadings should present and discuss all relevant arguments, facts and law asserted by each respondent and party to be material and relevant to the ED FIT proposal and issues.

Motions for hearing may be filed and served on the schedule stated below. Respondents and parties are reminded that pleadings must be verified; respondents and parties must use their best efforts to employ the same outline in their pleadings (in order to facilitate understandability, consistency and completeness); and motions for hearing must include certain specific information. (*See* September 26, 2008 Scoping Memo and Ruling, pages 7-9 and Ordering Paragraphs (OPs) 2, 3, 5 and 6.)

3. Official Notice

It is proposed that official notice be taken of the California Energy Commission (CEC) 2008 Integrated Energy Policy Report Update (California Energy Commission 2008, 2008 *Integrated Energy Policy Report Update*,

CEC-100-2008-008-CMF). (Rule 13.9 of the Commission's Rules of Practice and Procedure.) In particular, this includes elements that deal with the FIT such as, but not necessarily limited to, the Executive Summary and Chapter 1. Respondents and parties may comment.

4. Next Step

The record is composed (with limited exceptions) of documents and pleading formally filed in this proceeding with the Commission's Docket Office, and served on the service list. (*Id.*, pages 8-9 and OP 5.) This ruling puts the ED FIT Proposal in the record and provides for comments and reply comments. The comments and reply comments will be filed, and will become part of the record.

After receipt of these comments and replies, I anticipate preparing a proposed decision based on the complete record (*e.g.*, comments and reply comments from parties in July 2008, the March 2009 ED FIT Proposal, comments and reply comments on the ED FIT Proposal). I may later ask each respondent to prepare a draft FIT and standard contract to permit consideration of more specific or exact language, if necessary.[3]

IT IS RULED that:

1. Respondents shall, and parties may, file and serve comments and reply comments on the Energy Division Feed-In Tariff Proposal (Attachment A), proposed official notice, and anything else necessary for full consideration of the issues. For the purpose of this ruling, respondents are Pacific Gas and Electric

[3] For example, *see* March 12, 2007 Amended Scoping Memo and Ruling of Assigned Commissioner Regarding Implementation of Pub. Util. Code § 399.20 (Assembly Bill 1969). Also *see* November 18, 2008 Administrative Law Judge's Ruling Requiring Draft Revised Tariffs Based on Senate Bill 380.

Company, Southern California Edison Company, and San Diego Gas & Electric Company.

2. Comments shall be filed and served within 14 days of the date of this ruling. Reply comments shall be filed and served within seven days of the date of comments. Motions for hearing shall be filed and served within five days of the date reply comments are filed, and responses to motions within three days of motions.

Dated March 27, 2008, at San Francisco, California.

/s/ BURTON W. MATTSON
Burton W. Mattson
Administrative Law Judge

ATTACHMENT A

Feed-in Tariff for Renewable Generators Greater Than 1.5 MW

Energy Division Staff Proposal

March 27, 2009

1. Background

Public Utilities Code § 399.20 requires each electrical corporation to establish a tariff for the purchase of electricity from an eligible renewable electric facility at a market price determined by the Commission. The Commission implemented § 399.20 by establishing a Feed-In Tariff program (called a feed-in tariff since customers are "feeding into" the grid) in Decision (D.)07-07-027[4] on July 26, 2007. The decision adopted tariffs and standard contracts for the purchase of this electricity up to 1.5 MW from water and wastewater customers and other renewable customers.[5] The Commission's implementation of § 399.20 was considered Phase 1 of the Tariff and Standard Contract Implementation for RPS Generators. Resolution E-4137 approved the final Phase 1 tariffs and standard contracts and set the effective date of the tariffs as February 14, 2008. The Phase 1 utility tariffs also have a standard contract for the purchase of renewable energy product as its attachment.[6] The tariff is open to utility customers according to the terms of the program defined in D.07-07-027. Lastly, on September 28, 2008, SB 380 (Kehoe) amended Public Utilities Code § 399.20.[7] As a result of SB 380, the Commission is currently considering modifications to the existing program for generators up to 1.5 megawatts (MW).[8]

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[4] http://docs.cpuc.ca.gov/PUBLISHED/FINAL_DECISION/70660.htm

[5] The tariffs went into effect on February 14, 1008 with the adoption of Resolution E-4137.

[6] The Sierra Pacific tariff does not have a standard contract as an attachment.

[7] http://www.leginfo.ca.gov/pub/07-08/bill/sen/sb_0351-0400/sb_380_bill_20080928_chaptered.html

[8] This staff proposal does not contemplate modifications to the existing FIT program from 1 – 1.5 MW

On June 5, 2008, the Commission put forth in R.06-05-027[9] an Amended Scoping Memo and Ruling Regarding Phase 2 of Tariff and Standard Contract Implementation for RPS Generators.[10] The purpose of the scoping memo was to investigate various issues related to the feed-in tariff (FIT) program, including expanding the eligibility of the FIT contracts from 1.5 MW up to 20 MW. Parties filed comments on July 3, 2008.[11] Some parties indicated in their comments that there should be additional terms and conditions if the tariffs are going to be available to projects of a larger size. On October 10, 2008, Energy Division issued a Data Request to parties of R.08-08-009 for further information and received comments on October 24, 2008.[12] Based on the comments received, Energy Division issued a second Data Request on January 28, 2009 and received comments on February 4, 2009.

On February 10, 2009, Energy Division held a workshop regarding potential contract terms and conditions for the FIT program if it were expanded. The purpose of the workshop was to clarify party positions and identify areas of consensus regarding the terms and conditions for projects greater than 1.5 MW. Utilizing party responses to the data requests and comments at the February 10th workshop, a staff proposal for additional "terms and conditions" is outlined below. Since the content of those data requests is not currently part of the record of the proceeding, parties are welcome to repeat their responses to the data request(s) when they submit comments on this staff proposal.

2. Energy Division Staff Proposal Introduction

To help expedite consideration of FIT contract terms and conditions for projects greater than 1.5 MW, outlined below is a staff proposal from Energy Division that recommends specific terms and conditions. The Staff Proposal has three separate sections:

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[9] This rulemaking was closed on August 21, 2008, and superseded by R.08-08-009 (http://docs.cpuc.ca.gov/PUBLISHED/FINAL_DECISION/87123.htm)

[10] http://docs.cpuc.ca.gov/efile/RULC/83784.pdf

[11] http://docs.cpuc.ca.gov/published/proceedings/R0605027.htm#documents

[12] See FIT website to review the questions from the October 10, 2008 Data Request. http://www.cpuc.ca.gov/PUC/energy/Renewables/FITPhase2.htm

- General FIT program guiding principles that should be taken into consideration, to the extent possible, when developing FIT terms and conditions
- FIT program design elements that impact the FIT terms and conditions (e.g., project size)
- Specific FIT terms and conditions for projects greater than 1.5 MW

Staff proposes that additional terms and conditions apply to projects greater than 1.5 MW, and by *additional*, we assume that the existing feed-in tariffs already approved by the Commission serve as the starting point of each utility contract and that additional terms and conditions would be included if the project size is larger than 1.5 MW. This proposal does not suggest modifications to the existing terms and conditions of the existing utility contracts, all of which are available for renewable projects up to 1.5 MW.[13] See Appendix A for a comparison between the existing program and the staff proposal.

Lastly, this proposal does not suggest modifying the price paid under the FIT. Staff proposes to separately consider price in a new proceeding or as an additional phase in this proceeding, which is explained below (see Section 4.f).

3. FIT Guiding Principles

Staff proposes that the Commission consider the following general FIT program guiding principles, to the extent possible, when modifying the FIT program in the future. Staff introduces these guiding principles as a framework for making modifications to the existing FIT program. Staff does not assert that this staff proposal addresses all of the guiding principles below, since some of these guiding principles will be addressed during future phases of the FIT program. In general, the FIT program should:

1. Be open to all RPS-eligible technologies, but the program design elements should focus on technologies that possess sufficient renewable potential

[13] The existing FIT contracts can be accessed via the CPUC website: http://www.cpuc.ca.gov/PUC/energy/Renewables/hot/feedintariffs.htm

and scale to address state renewable and climate change goals within the 2020 timeframe.

2. Provide sufficient payment to stimulate untapped markets and build new projects, but not overpay or reduce the ability of competitive solicitations to put downward pressure on price.
3. Focus on projects of a certain size that can effectively mitigate the market and regulatory constraints (such as site control and permitting) that slow down development of larger renewable projects.
4. Be simple and transparent to the greatest extent possible and lower the transaction costs for the seller, buyer, and the regulator.
5. Equitably allocate risk, relative to project size, between the buyer and the seller.
6. Utilize long-term renewable planning to determine the appropriate total FIT program capacity and cost cap relative to the program's impact on greenhouse gas (GHG) reduction strategies, system reliability, and electricity rates.
7. Adopt program design elements and a contract that adequately address project viability.
8. Facilitate interconnection of projects that efficiently utilize the existing distribution system.
9. Compliment, but not impede or replace existing programs, especially the California Solar Initiative and the existing Renewable Portfolio Standard programs, which are both aimed at achieving the state's energy policy and climate change goals.
10. Provide some market certainty for project development, but also avoid creating a "boom and bust" market for renewable energy that brings many projects online quickly, but does not create a long-term sustainable marketplace for renewable energy.

4. FIT Program Design Issues

a. Utility Applicability

Staff proposes that the expanded feed-in tariff program only apply to the three large investor-owned utilities (IOUs), i.e., PG&E, SCE, and SDG&E, and not other CPUC jurisdictional investor-owned utilities.

Rationale: The small CPUC jurisdiction IOUs are too small to contract with multiple projects above 1.5 MW. Those IOUs can continue to utilize RPS program contracting process for all projects, including the existing 1.5 MW FIT, bilateral contracts, and competitive solicitations.

b. Eligible Generator Project Size

1.5 – 10 MW

Staff proposes expansion of the eligible generator project size in the existing must-take FIT program from 1.5 MW to 10 MW. Projects over 10 MW should not be eligible for a feed-in tariff. Consistent with the existing rules in the feed-in tariff program, the IOUs will not have to file an advice letter with the Commission upon execution of a feed-in tariff contract. The agreement will be effective according to the terms of the contract.

>10 – 20 MW

Staff also proposes that utilities be allowed to use a utility-specific standard-offer contract, which is not must-take, for >10 - 20 MW projects. The RPS proforma contract, which the IOUs submit with their yearly RPS procurement plans, could serve as the standard-offer contract. Once the Commission approves the proforma contract (which would happen at the same time that the Commission approves the yearly RPS procurement plans), the utility can use the proforma contract as a standard-offer contract for projects >10-20 MW. The IOUs will have discretion whether or not to sign the standard-offer contract. For all projects under this standard-offer agreement, the IOUs will only need to submit a Tier 2 advice letter to the Commission, which would become effective after 30 days unless the Commission suspends the advice letter. Since the Commission will not have an opportunity to review the viability of these larger sized contracts, the IOU cannot use these contracts for flexible compliance, i.e., justification for deferring RPS procurement obligations.

IOUs should also continue to procure projects over 10 MW through existing procurement mechanisms, including competitive solicitations or bilateral negotiations. Lastly, projects between 1.5 MW and 20 MW may choose to participate in the competitive solicitation process, if they believe the FIT (offered up to 10 MW) and the standard offer contract (offered between 10 and 20 MW) are not suited to their project needs.

Rationale: The scale and total project costs of a 10 MW project are large enough for a project developer to be able to effectively utilize the existing contracting processes that are available. Furthermore, as the size of a project increases from 1.5 to 20 MW, the impact on the distribution system increases. Staff worked with Energy and Environmental Economics (E3)[14] to determine the number of megawatts that could easily interconnect to the existing distribution substations without the need for upgrades. This analysis (see Appendix B) found that there is sufficient technical potential to make significant progress in reaching the RPS program goals. We estimated that there is about 5000 MW of solar PV potential to easily interconnect solar PV at little cost. The limit supports guiding principle #1, which proposes that a technology must possess sufficient renewable potential and scale to address state renewable and climate change goals. We also found that approximately 69% of the IOU distribution substations can interconnect projects 10 MW or smaller. Thus, a 10 MW limit supports guiding principle #8, which states that a FIT program should facilitate interconnection of projects that efficiently utilize the existing distribution system. Lastly, a 10 MW limit does not preclude full utilization of the distribution system if a substation can easily interconnect more than 10 MW. In that instance, the same distribution substation could serve more than one project.

In addition to efficient utilization of the distribution substation, limiting the FIT program to 10 MW and smaller supports guiding principle #3: focusing on smaller projects can effectively mitigate the market and regulatory constraints (such as site-control, permitting, and transmission-access) that impede development of larger renewable projects. Specifically, projects under 10 MW are not expected to need new transmission and are expected to have fewer environmental permitting and viability issues relative to projects greater than 10 MW. As a result, these projects should be able to come online within the 18 month project development window described below.

[14] http://www.ethree.com/home.html

c. Total Program Capacity Size Cap/ Wait-List

For projects 1.5 to 10 MW, staff recommends that 1000 MW be proportionately allocated across the utilities according to the share of coincident peak-demand. This program cap is in addition to the existing program capacity cap applicable to projects under 1.5 MW. The allocation methodology of using coincident peak-demand is the same methodology used in the current program, which was defined in D.07-07-027. Each utility will be able to sign-up projects for the tariff until the utility-specific capacity cap is reached. As is currently the case, the utilities will be required to publicly post the number of projects, the size of the projects, and other key information on their website. The utilities will also be required to keep a wait-list if the program cap is reached. If the program is fully subscribed, then projects will sign-up for the wait-list on a first-come first-serve basis. The Commission adopted this procedure in D.07-07-027.

As projects withdraw from the program or fail to meet commercial online date requirements, projects on the wait-list will have an opportunity to sign a FIT contract. This program cap is provisional and will remain in place until the Commission revisits the total FIT program capacity cap and IOU-specific allocation as part of long-term renewable planning. At that time, the Commission could consider raising or lowering the program capacity cap as it evaluates the appropriate mix of resources to ensure GHG reductions, system reliability, and just and reasonable rates.

> *Rationale:* Long-term renewable planning can properly balance the risk and cost offered by the generators in the FIT program. The CPUC currently evaluates the IOU RPS plans every year. This one year planning cycle will allow the CPUC to revisit the program cap for each IOU based on renewable resource need. In the meantime, a total program cap of 1000 MW is enough to see if there is sufficient program interest.

d. Length of Time to Achieve Commercial Operation

Projects that sign-up for the feed-in tariff currently have 18 months from the time the contract is executed to come online. We propose keeping this provision. We propose that the contract be automatically cancelled if it does not come online within 18 months from the date the contract is executed. We also propose allowing a one time 6 month extension if the project can successfully demonstrate that the cause of project delay was due to regulatory

processes, such as transmission or generator permitting, or interconnection. A generator must demonstrate that any regulatory delays were outside of its control by showing the necessary applications and fees were filed and paid on time. A delay due to business risk, such as lack of project financing or equipment delivery, is not a justification for granting an extension of the project's commercial operation date. Thus, a project has a maximum of 2 years to come online.

If a project fails to come online in 2 years, and there is still room available under the total program size cap for a new project to sign-up for the feed-in tariff, then the project can sign a new contract. If, on the other hand, the project fails to come online and there is a wait-list, the project will be placed at the end of the wait-list. FIT projects may also be eligible to bid into a competitive solicitation or negotiate a bilateral contract with an IOU if they encounter project development challenges at some point during the 18 month project development window.

> *Rationale*: A shortened project development window will help address project viability because, by default, only viable projects will be able to come online within the 18 month project development window. Conversely, the process for granting extensions due to regulatory delays outside of the generator's control will ensure that viable projects will not be canceled prematurely due to regulatory delays.

e. Uniform FIT contract terms

For projects between 1.5 and 10 MW, all three IOUs will have consistent terms and conditions that apply to larger projects. Each IOU shall start with its existing 1.5 MW FIT contract and add or amend identical existing terms and conditions for projects greater than 1.5 MW. The Commission will require the utilities to submit the uniform terms and conditions as part of this proceeding. Separately, the three utilities shall be required to work with each other and the parties to standardize all FIT terms and conditions across all three investor-owned utilities. The Commission should require that a uniform standard offer contract be filed with the Commission no later than July 1, 2010 and in effect no later than January 1, 2011.

> *Rationale:* While the existing 1.5 MW feed-in tariff contract is simple and short, each utility FIT contract is different. As we expand the program, it is important to move towards a more standardized approach to must-

take contacting across the three investor-owned utilities. The current proposal would have a set of uniform "additional terms and conditions" be added to the non-uniform existing feed-in tariff contracts. Ultimately, the Commission should require uniform standard contracts for all terms. Having standard contract terms for projects below 10 MW will increase the transparency of the program and lower the transaction costs for the buyer, seller, and the regulator.

f. FIT contract price

Staff recognizes that the price level and rate structure of the proposed FIT is an essential element to the success of the program. A future phase of this proceeding will address what the appropriate price should be.

Rationale: This will give the Commission additional time to carefully balance the cost, risk and timing of the overall RPS Program with the cost, risk and timing of an expanded FIT Program.

g. Excess Sales versus Full Export

In D.07-07-027, the Commission authorized two options under the FIT program: full export and net excess sales. Full export is similar to the European model where all of the energy production is sold to the buyer. FIT projects using net excess sales first serve their own load and then sell the remaining energy production to the buyer. We propose that the expanded FIT program only be available as a full export tariff.

Rationale: The net excess sales option does not provide the utility sufficient certainty regarding the expected electricity output of the renewable projects. This uncertainty undermines guiding principle #6, which states that the IOUs should utilize long-term renewable planning to determine the appropriate total FIT capacity and cost cap relative to the program's impact on GHG reduction strategies, system reliability, and electricity rates. Allowing projects to serve their load first will undermine the IOUs' ability to effectively conduct long-term renewable planning.

5. Additional Terms and Conditions for Projects between 1.5 MW and 10 MW

a. Location Restriction

Any project is eligible for the feed-in tariff offered by any IOU if the project is developed within the CAISO control area.

> *Rationale:* This will provide generators the flexibility to site projects where they can (1) quickly and cost-effectively interconnect at the distribution level and (2) utilize higher quality renewable resources. However, project sponsors are not allowed to submit multiple projects to multiple utilities, utilizing the same project site. Transparent reporting of existing contracts will be available on each utility website in order to prevent a project sponsor from submitting the same project to multiple utilities.

b. Project Milestones

The only project milestone that the project sponsor needs to guarantee is the commercial online date. The project sponsor must submit a project development milestone timeline to the utility upon signing the FIT contract and provide quarterly milestone progress reports to the IOU so that the IOU and Commission can monitor project development progress.

> *Rationale*: The shortened project development window will help ensure project viability by forcing projects to come online quickly (commercial online date milestone) or be removed from the FIT program. This approach gives the project sponsor flexibility in achieving the other project milestones, but still provides the IOUs a firm guarantee that a project will either come online or be canceled within 18 months, assuming that an extension is not granted due to regulatory delays (see section 4.d).

c. Project Development Security

Projects must post a project development security of $20/kilowatt ($30,000 – $200,000, assuming a 10 MW program cap) at the time of signing the contract.

> *Rationale*: Generators posting project development security upon signing the contract will help ensure project viability. In addition, project development security mitigates the risk of non-viable projects

fully subscribing the program cap and, effectively, preventing more viable projects from signing a FIT contract.

d. Performance Assurance/Delivery Term Security

The performance assurance/delivery term security would be zero for projects 1.5 – 5 MW and 5% of expected total project revenue for projects greater than 5 MW.

Rationale: Performance assurances mitigate the risk of a generator not honoring its contractual arrangements with the utility after the project has come online. It also provides the IOU with a mechanism to quickly collect performance security with minimal litigation risk.

e. Performance Obligation/Energy Delivery Obligation

The current FIT contracts have language that support this term. For example, current FIT contracts allow the IOUs to terminate a contract if the generator does not deliver within a specified timeframe. The existing contracts also require the seller to maintain and operate the facility according to good utility practice or prudent electrical practices. We propose keeping this existing language, but adding an explicit term for performance obligation so that generators must meet a minimum threshold for utility planning purposes. We propose the performance obligation to be 140% of expected annual net energy production based on two years of rolling production. In addition, utilities will bear the risk of scheduling deviations if the generator 1) participates in the California Independent System Operator's Participating Intermittent Resource Program (PIRP), 2) provides the utility, as scheduling coordinator, with timely information on its availability, or 3) provides the utility with remote access to metered output.

Rationale: If the utilities are required to enter into 10 to 20 year FIT contracts, they need to be able to count on the energy deliveries in the future to effectively conduct long-term renewable planning. Thus, a minimum threshold is needed.

f. Damage Calculation

Capped damages should be equal to contract energy price minus average market price for the term year, but not greater than $0.05 nor less than $0.02/kWh.

Rationale: Damage calculation is needed to enforce a performance obligation/energy delivery obligation (section e). Damages should be capped to ensure financeability and investor certainty.

g. Force Majeure and Events of Default

These terms must be included in the FIT contract for projects between 1.5 MW and 10 MW.

Rationale: These terms protect the buyer and seller from events outside of their control.

h. Insurance

These terms should continue as same requirements as existing FIT contracts

Rationale: Existing insurance requirements are adequate even if the size of project expands.

i. FERC Certification

Current SCE and SDG&E standard contracts require the generator to register with the Federal Energy Regulatory Commission (FERC) as a Qualifying Facility (QF). Independently of the tariff/standard contract, PG&E requires the generator to obtain certification at FERC as either a QF or exempt wholesale generator. This language should be removed from the IOU FIT contract, tariff, and related documents.

Rationale: The generator may or may not need to obtain certification from FERC, but that is not a requirement of eligibility for the Commission-approved FIT. In addition, the generator (and not the IOU) should choose which certification option is in the generator's best interest.

Appendix A: Comparison Between Existing FIT Program and Staff Proposal

	Existing FIT program (0 - 1.5 MW)	**Staff proposal for FIT program expansion (>1.5 MW to 10 MW)**
Program Design Issues		
Utility Applicability	All CPUC jurisdictional IOUs	Only the 3 large IOUs: PG&E, SCE, and SDG&E
Total Program Size Cap	500 MW	Additional 1000 MW for all projects in this category
Contract Price	Market price referent	No change
Location Restrictions	Must be an IOU retail customer	Must be within CAISO Controlled Grid
FIT contract terms	Each IOU developed own language based on D.07-07-027	New terms and conditions must be the same across all 3 IOUs
Contract Terms and Conditions		
Length of Time to Achieve Commercial Operation	Within 18 months, with opportunity to extend online date	Within 18 months, with opportunity to extend online date by 6 months for regulatory delays
Excess Sales/Full Export	Projects can choose either excess sales or full export	No choice, all producers must export all energy production
Development Security	None	$20/kW
Performance Assurance	None	5% of expected total project revenue for projects (only applies to >5 MW – 10 MW)
Performance Obligation/Energy Delivery Obligation	Utility can terminate contract if deliveries are not made according to good utility practice or prudent electrical practices	Add minimum requirement: 140% of expected annual net energy production based on two years of rolling production
Damage Calculation	Damages are actual direct damages; they are neither calculated by a formula nor capped	Capped damages equal to contract energy price minus average market price for the term year, but not greater than $0.05 nor less than $0.02/kWh
Insurance	SCE/SDG&E: $2 million (>100 kW) PG&E: $1 million (>100 kW)	No change
FERC Certification	IOUs currently require FERC Certification	Not required

Appendix B: Determination of Appropriate Feed-in Tariff Size

Background and Stakeholder Process

Energy Division staff determined the 10 MW feed-in tariff project size limit based on the information and analysis gained in the 33% RPS Implementation Analysis[15] completed in the Long-Term Procurement Plans (LTPP) proceeding. In this proceeding, Energy Division worked with the consulting firm Energy and Environment Economics (E3)[16] and formed a working group to study a 'Transmission Constrained Scenario' to evaluate meeting a 33% RPS requirement without the construction of new large transmission lines. Parties included the utilities and utility distribution engineers, ratepayer advocates and environmental groups (PG&E, SDG&E, SCE, Community Environment Council, First Solar, and Greenvolts). Energy Division held a workshop on December 16, 2008 to review preliminary results, and parties filed comments on the analysis, which were incorporated into the analysis.

Methodology

In the assessment of a transmission constrained scenario, an estimate of achievable potential for photovoltaics (PV) was developed by evaluating a number of 'screens'. While the gross potential of solar resource in California is vast, the analysis also considered the following criteria to develop achievable potential:

1. Suitable Sites
    - In urban areas;
        - Available large roof area (greater than 0.5 acre flat roof)
    - In rural areas;
        - Available land with low slopes near substations
2. Willing Customers

[15] http://www.cpuc.ca.gov/PUC/energy/Renewables/hot/33implementation.htm

[16] www.ethree.com

- Participation percentage among suitable host sites

3. Ability to 'easily' interconnect to the distribution system

The third screen evaluated the potential to 'easily' interconnect, which provides the basis for establishing the appropriate feed-in tariff size.

The methodology for establishing this was done in the following manner.

1. Define criteria for 'easily' interconnect. Consistent with the purpose of a feed-in tariff, the potential for 'easy' interconnection in the LTPP proceeding was done such that the renewable project (a) makes use of existing distribution system without significant upgrades, and (b) is likely to be built within a relatively short time-horizon.

2. Establish the size range of PV systems that meet criteria. The working group relied heavily on the Rule 21 interconnection standard to define size range of interconnection.[17] Rule 21 specifies maximum generator size relative to the peak load on the load at the point of interconnection at 15%. So, for example, if a generator is interconnected on the low side of a distribution substation bank with a peak load of 20 MW, the maximum Rule 21 interconnection criteria would allow a 3 MW system (3 MW = 15% * 20 MW).

However, the 15% criterion, which is established for all generators regardless of type, was adjusted to 30% for the purposes of determining the technical potential of PV. The 15% limit is established at a level where it is unlikely the generator would have a greater output than the load at the line segment, even in the lowest load hours in the off-peak hours and seasons (such as the middle of the night and in the spring). Since the peak output for photovoltaics is during the middle of the day, PV is unlikely to have any output when loads are lowest. Therefore, a 30% criterion was used for technical interconnection potential estimates. The discussion was held with utility distribution engineers, however, we did not consider formal engineering studies or Rule 21 committee deliberation since the purpose of the analysis was only to define potential.

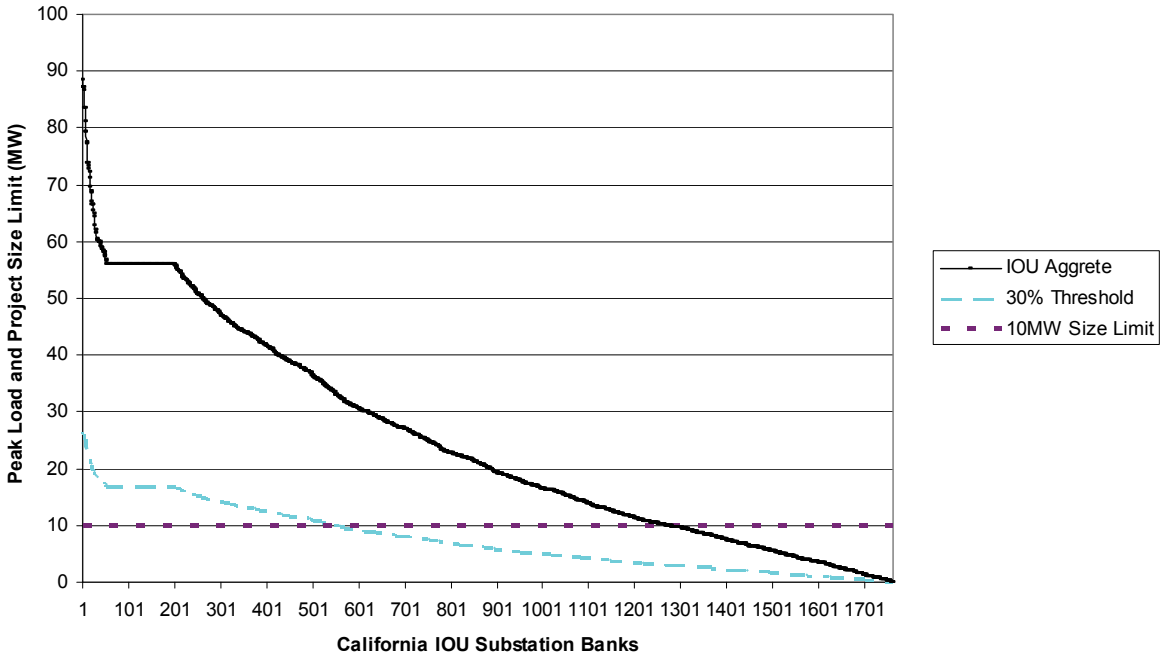
[17] http://www.energy.ca.gov/distgen/interconnection/california_requirements.html

3. Gather utility substation data on peak loading. With the size criteria, we gathered peak load data from distribution substation banks and substations for all of the IOUs for all distribution substations. The maximum size of 'easy' interconnection is then defined by a range of distribution substation bank loads, and the size threshold.

Results

Figure 1 below, compares the 30% size criteria to the substations for each utility distribution substation. The graph shows the maximum size for PV project interconnection if connected directly to the distribution substation bank. From this analysis, it appears that the 10 MW PV system size is the largest possible for the vast majority of distribution system interconnections. If the PV generator is connected at a different point closer to the end of a distribution feeder where the load is lower, then the allowable size of the PV installation would be smaller. However, it is unlikely that a PV system larger than this size can be readily interconnected in a streamlined process.

Figure 1: Comparison of Investor-owned Utility Bank Peak Loads, 30% Threshold and 10 MW Feed-in Tariff Size limit[18]



[18] Note that the chart is adapted from 12/16/08 Workshop presentation for the 33% RPS Implementation Analysis

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Dated March 27, 2009, at San Francisco, California.

/s/ ERLINDA PULMANO
Erlinda Pulmano

Bill Powers

From: Mark Martyak [mmartyak@powersecure.com]
Sent: Wednesday, January 13, 2010 5:30 PM
To: bpowers@powersengineering.com
Subject: Re: ballpark cost of upgrading older distribution substations for full bidirectional flow

Probably 4 per. For a 100MW 16 CB Station you are looking at 400 to 450K. Mark

---

From: Bill Powers
To: Mark Martyak; Donna Zino
Sent: Wed Jan 13 18:28:17 2010
Subject: RE: ballpark cost of upgrading older distribution substations for full bidirectional flow

Mark,

Thank you for this estimate. A typical 12 kV/69 kV distribution substation out here (Southern California) typically has four 25 MW load banks. I do not know enough about breaker configurations for distribution substations to know offhand the number of breakers for a substation of this type. I am presuming there is one breaker per load bank.

Regards,

Bill Powers, P.E.
Powers Engineering
4452 Park Blvd., Suite 209
San Diego, CA 92116

tel: 619-295-2072
fax: 619-295-2073
cell: 619-917-2941

From: Mark Martyak [mailto:mmartyak@powersecure.com]
Sent: Wednesday, January 13, 2010 8:56 AM
To: Donna Zino
Cc: bpowers@powersengineering.com
Subject: RE: ballpark cost of upgrading older distribution substations for full bidirectional flow

Bill,

The total cost per substation would be dependent on the number of breakers and existing condition and configuration. A ballpark in the $30- $40K per breaker should be expected. Mark

---

From: Donna Zino
Sent: Monday, January 11, 2010 4:13 PM
To: Mark Martyak
Subject: FW: ballpark cost of upgrading older distribution substations for full bidirectional flow

Fyi,

From: Bill Powers [mailto:bpowers@powersengineering.com]
Sent: Monday, January 11, 2010 4:09 PM

To: Donna Zino
Subject: ballpark cost of upgrading older distribution substations for full bidirectional flow

Hello Donna,

Thank you for your help on this. – Bill Powers

From: Bill Powers [mailto:bpowers@powersengineering.com]
Sent: Monday, January 11, 2010 12:25 PM
To: 'whartmann@powersecure.com'
Subject: ballpark cost of upgrading older distribution substations for full bidirectional flow

Wayne:

I read online the excellent presentation you gave last September titled “Meeting the Challenges of Smart Grid in Distribution Substations.” I am an advocate of much greater usage of distributed PV at the distribution substation level nationwide to address peak loads and greenhouse gas emissions reduction. Two articles I have written for Natural Gas & Electricity Journal on this subject are attached.

My question for you is the ballpark cost of upgrading older distribution substations to full bidirectional flow, to permit interconnection of DG up to the distribution substation rated capacity. Here in California policy discussions, 15% or 30% of peak capacity is identified as the ceiling for DG inflows presuming indefinite use of unidirectional substation powerflows.

A colleague of mine that works in T&D for Nevada Power indicated in conversation that NP has recently upgraded a distribution substation to full bidirectional flow for ~$300,000. $30,000 to $40,000 was used to upgrade the protective relays, and ~$250,000 was used to outfit the substation with a full digital communication/telemetry package.

I am trying to determine if an investment of up to ~$500,000 would be sufficient to upgrade an older 100 MW distribution substation for full bidirectional flow.

Regards,

Bill Powers, P.E.
Powers Engineering
4452 Park Blvd., Suite 209
San Diego, CA 92116

tel: 619-295-2072
fax: 619-295-2073
cell: 619-917-2941

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In the Matter of the Application of San Diego
Gas & Electric Company (U-902-E) for a
Certificate of Public Convenience and Necessity
For the Sunrise Powerlink Transmission Project

Application No. 06-08-010
Exhibit No.: _____

CHAPTER 5
PREPARED REBUTTAL TESTIMONY
OF SAN DIEGO GAS & ELECTRIC COMPANY
IN RESPONSE TO PHASE 2 TESTIMONY
OF POWERS ENGINEERING

BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF CALIFORNIA

March 28, 2008

Response to SDG&E's DR 3-11). His proposal ignores both the impacts and cost associated with mitigating these impacts.

While Mr. Powers admits the concept of renewable energy parks are hypothetical, as discussed above there would be cost impacts associated with these parks. Mr. Powers was not able to identify the locations or sizes of any of the proposed "renewable energy parks" or commercial scale PV installations. Ignoring for the moment the time required to complete regulatory filings for the T&D upgrades necessary, SDG&E has developed a conceptual estimated cost of installing new infrastructure and/or upgrading existing infrastructure to support the interconnection of 920 MW PV generated power to the 69 kV network. This rough cost, absent AFUDC, land, and regulatory compliance filings, is estimated to be between $345 and $406 million. This cost is in addition to the cost of installing, replacing, operating and maintaining PV facilities. This cost would be borne by SDG&E rate payers. SDG&E investigated two possible scenarios for interconnecting PV generation to SDG&E 69 kV network and based the cost estimates on the following assumptions:

- PV generated power is connected to the 12 kV distribution feeders, stepped up to 69kV at the substations that are connected to the 69 kV network
- New substations are 69/12 kV, rated 100 MW per substation. Estimated construction cost: $25 - 30 million per substation
- New distribution feeders are within one mile of a new substation
- Existing distribution feeders are within five mile of an existing substation
- Maximum rating of a distribution feeder is 10 MW
- Estimated new construction or upgrade cost is $0.6 million per mile for distribution feeders

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Re-DEC Working Group Meeting

Straw proposal of solution to address short-term problem of information gap

December 9, 2009

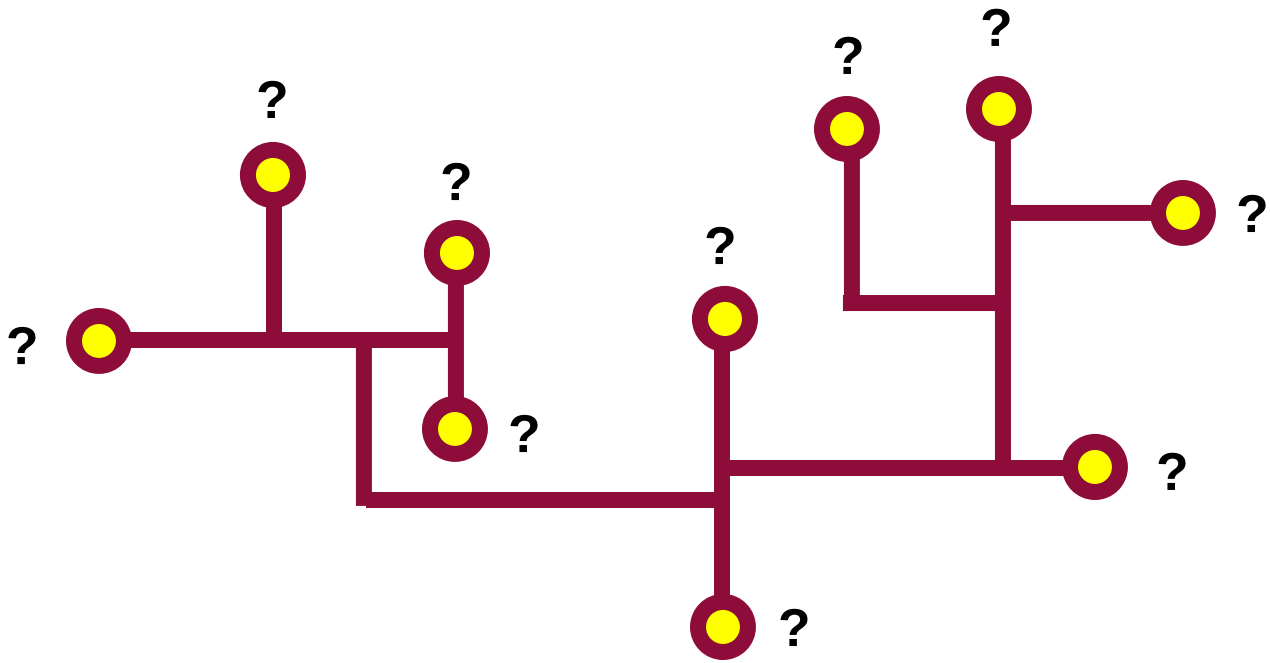
Purpose

Encourage discussion of potential solutions to address the lack of information on preferred interconnection locations

Straw proposal is only initial concept – definitely room for improvement and modification

Challenge Articulation

- Siting: Identifying sites with low interconnection costs may be difficult for developers because they do not have sufficient information from utilities.



Challenge Articulation

- Siting: Identifying sites with low interconnection costs may be difficult for developers because they do not have sufficient information from utilities.

Shared Goals

- We want to install renewable DG in the locations with the:
  - Lowest cost
  - Maximum benefit
  - Without compromising system protection, safety, and reliable operation
- These goals are shared by the utility, developer, and ratepayers

…Alternatively said

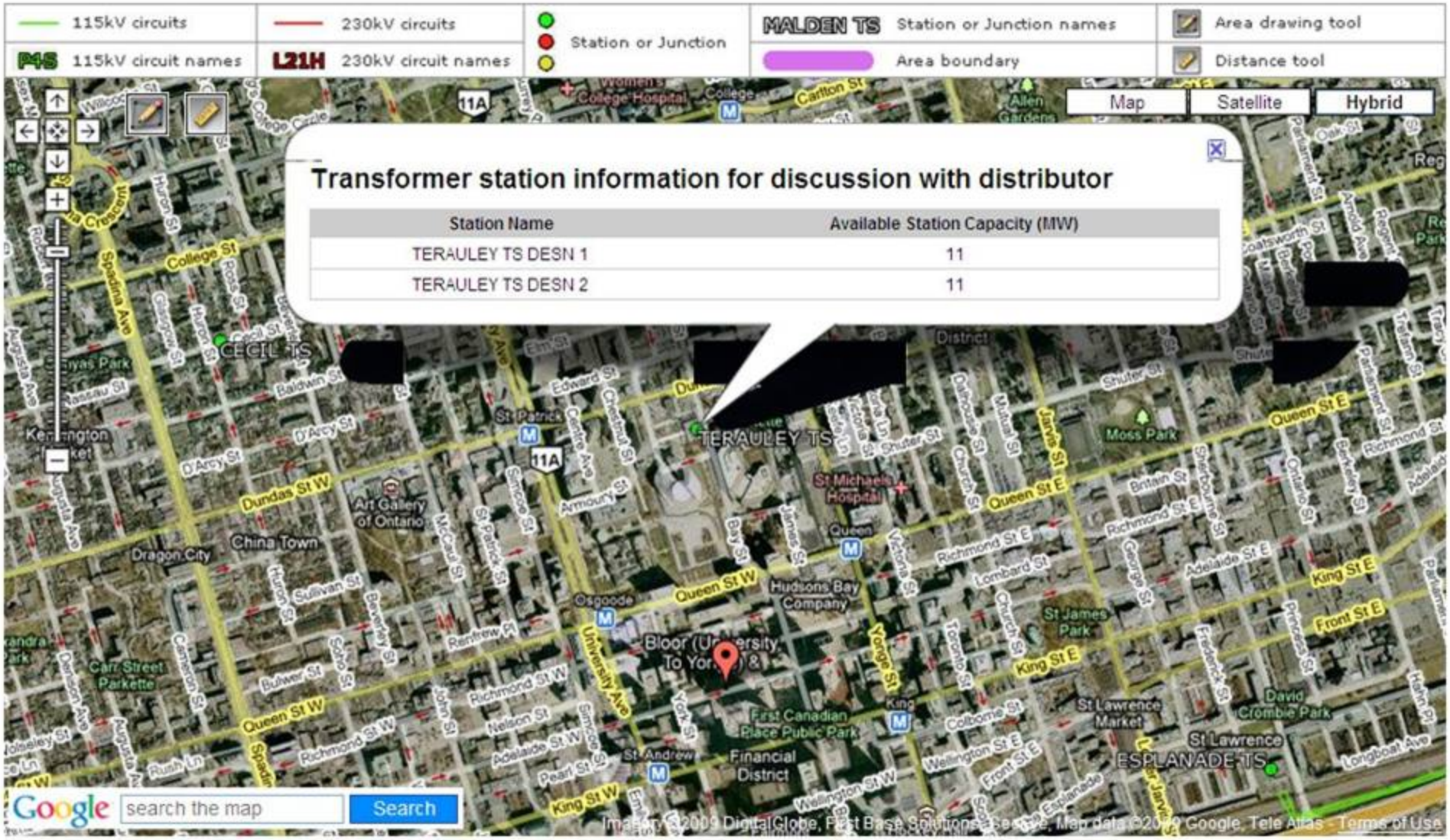
- We want to achieve 100% successful interconnection application rates
  - Developers benefit
  - Utilities benefit
  - Ratepayers benefit
- What information can be provided to do this?

Information Developers Would Likely Find to Be Valuable

- Location of distribution substations and feeders (specific coordinates / GIS)
- Transformer ratings and including high and low side voltages
- Substation short circuit duty
- Substation / feeder loads: peak and minimum loads

- OR – Just tell me where I can interconnect my system at minimal cost

Ontario Power Authority Example



Ontario Power Authority Renewable Energy Feed-in Tariff Program System Map Tool

Information Concerns

- Security / commercial sensitivity
  - Providing details on distribution system could compromise homeland security
  - Information on peak loads and system configuration may be considered commercially sensitive
- Alternative review process
  - Current process requires formal review – liability concerns for "casual" guidance
  - May only be able to provide general guidelines for developers – no guarantee that interconnection is feasible
    - Study would most likely still be required
- Timely information – distribution system somewhat dynamic, loads constantly changing, new DG installations
- Millions of potential interconnection points

Straw Proposal to Bridge Information Gap

(Adapted from SMUD concept)

1. Criteria established to identify MW that might be accommodated at "no cost" based on existing feeder conditions
   - 15% of peak? 30% of peak? 80% of minimum load?
   - DG systems over the size threshold listed above will be more likely to require upgrades (subject to study)
2. Utilities evaluate potential DG interconnection per feeder based on criteria
3. Feeders linked to individual County Assessor parcels using GIS

Straw Proposal to Bridge Information Gap
(continued)

4. Parcels "color-coded" based on potential DG that can be interconnected
   - For example: 0 MW, <1 MW, <3 MW, etc.
5. Developers query parcel information or review online maps
6. Developers file interconnection request for promising parcels (normal process resumes)
7. Information updated regularly (annual, semi-annually, ?)

Straw Proposal Example for Carson, CA

Imagery: Google Maps

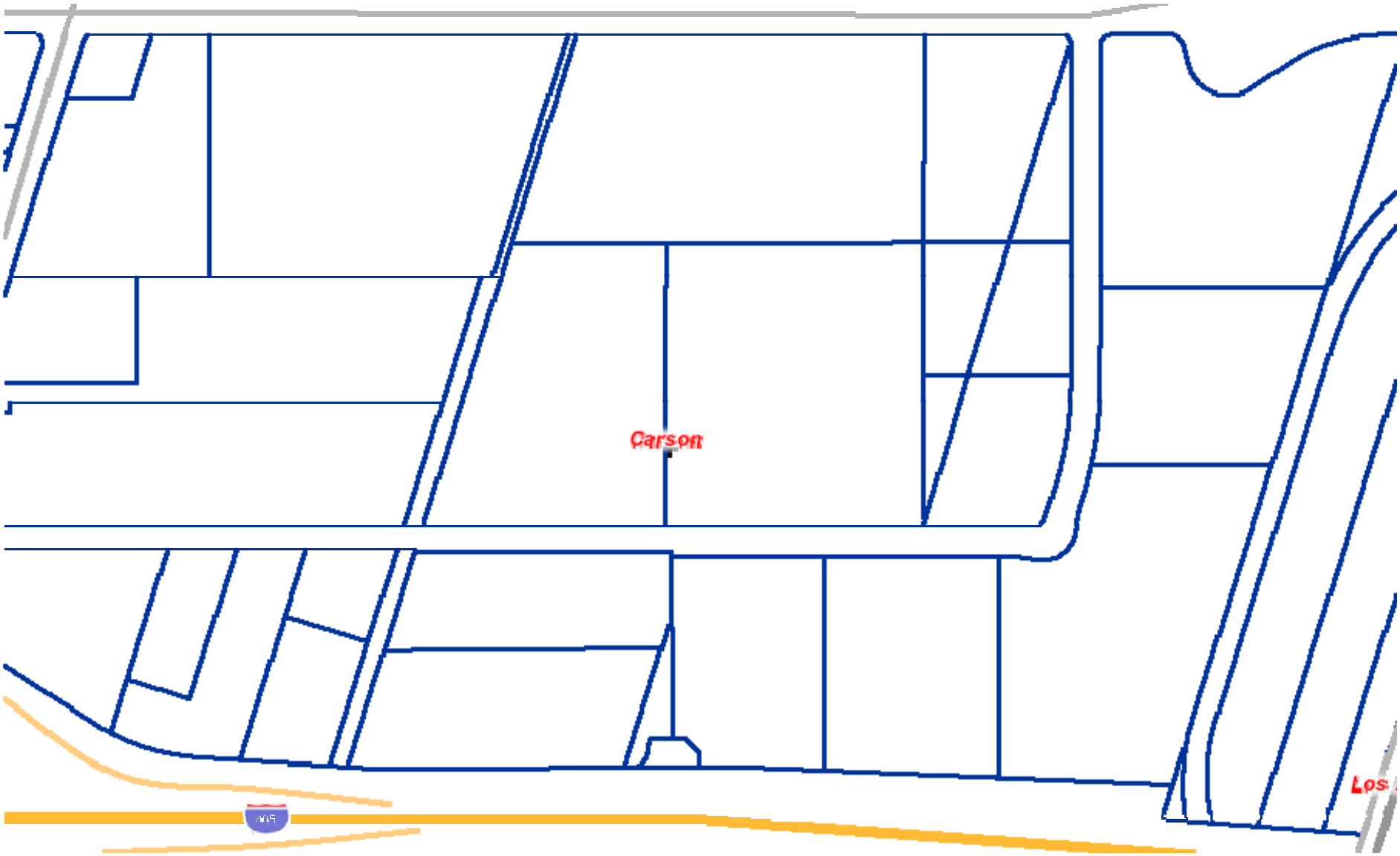
Hypothetical, For Example Only

Straw Proposal Example for Carson, CA

Imagery: Google Maps

Hypothetical, For Example Only

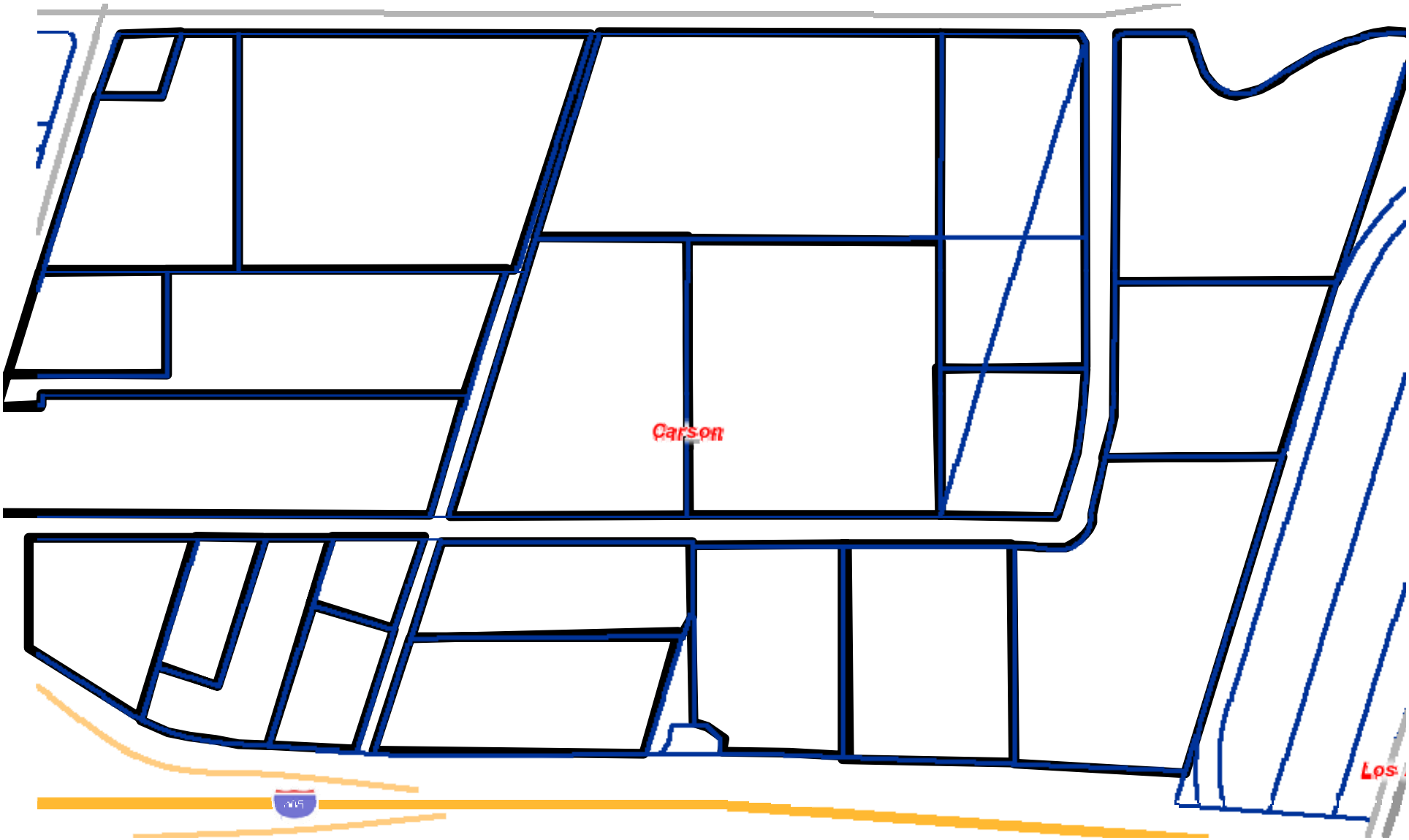
Parcel Information



Imagery: LA County GIS-NET

Hypothetical, For Example Only

Metered Parcels



Hypothetical, For Example Only

Metered Parcels

Hypothetical, For Example Only

Potential DG Interconnection

Hypothetical, For Example Only

Discussion and Comments

The New York Times

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August 9, 2009

Climate Change Seen as Threat to U.S. Security

By JOHN M. BRODER

WASHINGTON — The changing global climate will pose profound strategic challenges to the United States in coming decades, raising the prospect of military intervention to deal with the effects of violent storms, drought, mass migration and pandemics, military and intelligence analysts say.

Such climate-induced crises could topple governments, feed terrorist movements or destabilize entire regions, say the analysts, experts at the Pentagon and intelligence agencies who for the first time are taking a serious look at the national security implications of climate change.

Recent war games and intelligence studies conclude that over the next 20 to 30 years, vulnerable regions, particularly sub-Saharan Africa, the Middle East and South and Southeast Asia, will face the prospect of food shortages, water crises and catastrophic flooding driven by climate change that could demand an American humanitarian relief or military response.

An exercise last December at the National Defense University, an educational institute that is overseen by the military, explored the potential impact of a destructive flood in Bangladesh that sent hundreds of thousands of refugees streaming into neighboring India, touching off religious conflict, the spread of contagious diseases and vast damage to infrastructure. “It gets real complicated real quickly,” said Amanda J. Dory, the deputy assistant secretary of defense for strategy, who is working with a Pentagon group assigned to incorporate climate change into national security strategy planning.

Much of the public and political debate on global warming has focused on finding substitutes for fossil fuels, reducing emissions that contribute to greenhouse gases and furthering negotiations toward an international climate treaty — not potential security challenges.

But a growing number of policy makers say that the world’s rising temperatures, surging seas and melting glaciers are a direct threat to the national interest.

If the United States does not lead the world in reducing fossil-fuel consumption and thus emissions of global warming gases, proponents of this view say, a series of global

environmental, social, political and possibly military crises loom that the nation will urgently have to address.

This argument could prove a fulcrum for debate in the Senate next month when it takes up climate and energy legislation passed in June by the House.

Lawmakers leading the debate before Congress are only now beginning to make the national security argument for approving the legislation.

Senator John Kerry, the Massachusetts Democrat who is the chairman of the Foreign Relations Committee and a leading advocate for the climate legislation, said he hoped to sway Senate skeptics by pressing that issue to pass a meaningful bill.

Mr. Kerry said he did not know whether he would succeed but had spoken with 30 undecided senators on the matter.

He did not identify those senators, but the list of undecided includes many from coal and manufacturing states and from the South and Southeast, which will face the sharpest energy price increases from any carbon emissions control program.

“I’ve been making this argument for a number of years,” Mr. Kerry said, “but it has not been a focus because a lot of people had not connected the dots.” He said he had urged President Obama to make the case, too.

Mr. Kerry said the continuing conflict in southern Sudan, which has killed and displaced tens of thousands of people, is a result of drought and expansion of deserts in the north. “That is going to be repeated many times over and on a much larger scale,” he said.

The Department of Defense’s assessment of the security issue came about after prodding by Congress to include climate issues in its strategic plans — specifically, in 2008 budget authorizations by Hillary Rodham Clinton and John W. Warner, then senators. The department’s climate modeling is based on sophisticated Navy and Air Force weather programs and other government climate research programs at NASA and the National Oceanic and Atmospheric Administration.

The Pentagon and the State Department have studied issues arising from dependence on foreign sources of energy for years but are only now considering the effects of global warming in their long-term planning documents. The Pentagon will include a climate section in the Quadrennial Defense Review, due in February; the State Department will address the issue in its new Quadrennial Diplomacy and Development Review.

"The sense that climate change poses security and geopolitical challenges is central to the thinking of the State Department and the climate office," said Peter Ogden, chief of staff to Todd Stern, the State Department's top climate negotiator.

Although military and intelligence planners have been aware of the challenge posed by climate changes for some years, the Obama administration has made it a central policy focus.

A changing climate presents a range of challenges for the military. Many of its critical installations are vulnerable to rising seas and storm surges. In Florida, Homestead Air Force Base was essentially destroyed by Hurricane Andrew in 1992, and Hurricane Ivan badly damaged Naval Air Station Pensacola in 2004. Military planners are studying ways to protect the major naval stations in Norfolk, Va., and San Diego from climate-induced rising seas and severe storms.

Another vulnerable installation is Diego Garcia, an atoll in the Indian Ocean that serves as a logistics hub for American and British forces in the Middle East and sits a few feet above sea level.

Arctic melting also presents new problems for the military. The shrinking of the ice cap, which is proceeding faster than anticipated only a few years ago, opens a shipping channel that must be defended and undersea resources that are already the focus of international competition.

Ms. Dory, who has held senior Pentagon posts since the Clinton administration, said she had seen a "sea change" in the military's thinking about climate change in the past year. "These issues now have to be included and wrestled with" in drafting national security strategy, she said.

The National Intelligence Council, which produces government-wide intelligence analyses, finished the first assessment of the national security implications of climate change just last year.

It concluded that climate change by itself would have significant geopolitical impacts around the world and would contribute to a host of problems, including poverty, environmental degradation and the weakening of national governments.

The assessment warned that the storms, droughts and food shortages that might result from a warming planet in coming decades would create numerous relief emergencies.

"The demands of these potential humanitarian responses may significantly tax U.S. military transportation and support force structures, resulting in a strained readiness posture and decreased strategic depth for combat operations," the report said.

The intelligence community is preparing a series of reports on the impacts of climate change on individual countries like China and India, a study of alternative fuels and a look at how major power relations could be strained by a changing climate.

"We will pay for this one way or another," Gen. Anthony C. Zinni, a retired Marine and the former head of the Central Command, wrote recently in a report he prepared as a member of a military advisory board on energy and climate at CNA, a private group that does research for the Navy. "We will pay to reduce greenhouse gas emissions today, and we'll have to take an economic hit of some kind.

"Or we will pay the price later in military terms," he warned. "And that will involve human lives."

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Application: 09-02-
(U 39 E)
Exhibit No.: (PG&E-1)
Date: February 24, 2009
Witnesses: Doug Herman
Garrett P. Jeung
Michael L. Jones
Brian M. McDonald
Joseph F. O'Flanagan
Fong Wan

PACIFIC GAS AND ELECTRIC COMPANY

PHOTOVOLTAIC PROGRAM

PREPARED TESTIMONY

PACIFIC GAS AND ELECTRIC COMPANY
PHOTOVOLTAIC PROGRAM

TABLE OF CONTENTS

Chapter	Title	Witness	Page
1	POLICY CHAPTER: EXECUTIVE SUMMARY AND OVERVIEW OF APPLICATION	Fong Wan	
	A. Introduction		1-1
	B. Program Overview		1-2
	1. PV UOG Program		1-2
	2. PV PPA Program		1-3
	3. PV Pilot Project		1-4
	C. Rationale for the PV Program		1-5
	1. The PV Program Supports California and Federal Environmental Goals		1-5
	2. Utility Ownership of PV, Coupled With a Similar PPA Program, Is Appropriate and Beneficial for Customers		1-6
	D. Testimony Overview		1-8
	E. Conclusion		1-9
2	PHOTOVOLTAIC UTILITY-OWNED GENERATION PROGRAM	Brian M. McDonald	
	A. Introduction		2-1
	B. Outline of Program		2-1
	C. Size		2-2
	D. Timing		2-2
	E. Location		2-3
	F. Technology		2-4
	G. Interconnection		2-5
	H. Implementation		2-6
	I. Conclusion		2-7
3	PHOTOVOLTAIC POWER PURCHASE AGREEMENT PROGRAM	Garrett P. Jeung	
	A. Introduction		3-1
	B. Outline of Program		3-1
	C. Timing and Timeline		3-2
	D. Eligibility		3-2

PACIFIC GAS AND ELECTRIC COMPANY
PHOTOVOLTAIC PROGRAM

TABLE OF CONTENTS

(CONTINUED)

Chapter	Title	Witness	Page
	1. Technology		3-3
	2. Project Size		3-3
	3. New Projects		3-3
	4. Location of Generating Facility		3-4
	E. RFO Selection Process		3-4
	1. Project Viability		3-4
	2. Market Valuation		3-5
	3. Credit		3-5
	4. RPS Goals		3-5
	F. General Contract Terms		3-5
	G. Pricing		3-8
	H. Regulatory Approval		3-8
	I. Conclusion		3-9
4	CAPITAL COSTS	Doug Herman	
	A. Introduction		4-1
	B. Summary		4-1
	C. Global Assumptions		4-3
	D. PV System Contract Cost		4-4
	E. Land Acquisition, Site Preparation and Permitting		4-4
	F. Grid Interconnection		4-5
	G. Security and SCADA		4-6
	H. PG&E Supervisory Labor, Consulting Support, Permits		4-6
	I. Contingency		4-6
	J. Pilot Project		4-6
	K. Conclusion		4-7
5	OPERATIONS AND MAINTENANCE COSTS	Michael L. Jones	
	A. Operations and Maintenance Costs: Photovoltaic Utility-Owned Generation Program		5-1

PACIFIC GAS AND ELECTRIC COMPANY
PHOTOVOLTAIC PROGRAM

TABLE OF CONTENTS

(CONTINUED)

Chapter	Title	Witness	Page
	1. Introduction		5-1
	2. Summary		5-1
	3. Basis of Design and Cost Assumptions		5-2
	4. Description of O&M Costs		5-3
	a. PG&E Labor and Preventive Maintenance		5-3
	b. Safety, Security and Compliance		5-4
	c. Infrastructure		5-4
	d. Consumables and Materials		5-5
	e. Corrective Maintenance		5-5
	f. Contracts: Panel Washing		5-5
	g. Contracts: Vendor Service Agreement		5-6
	5. Contingency on O&M Costs		5-6
	B. PV Pilot Project O&M Costs		5-6
	C. Conclusion		5-7
6	REVENUE REQUIREMENT AND RATEMAKING FOR PG&E'S PHOTOVOLTAIC PROGRAM	Joseph F. O'Flanagan	
	A. Introduction		6-1
	B. Ratemaking Proposal for PV Programs		6-1
	1. Ratemaking Proposal for 250 MW PV UOG Program		6-2
	a. Recovery of Initial Capital Costs		6-2
	b. Initial Revenue Requirement		6-3
	c. Adjustments to Initial Revenue Requirement		6-5
	2. Ratemaking Proposal for PV Pilot Project		6-5
	3. Ratemaking Proposal for Land Deposits		6-6
	4. PV PPA Program Cost Recovery		6-6
	5. Non-Bypassable Charge		6-7
	C. Development of PV Program Revenue Requirements		6-7

PACIFIC GAS AND ELECTRIC COMPANY
PHOTOVOLTAIC PROGRAM

TABLE OF CONTENTS

(CONTINUED)

Chapter	Title	Witness	Page
	1. 250 MW PV UOG Program Revenue Requirement		6-7
	2. Development of Average Revenue Requirement per MW		6-8
	a. Operation and Maintenance		6-9
	b. Uncollectibles and Franchise Expense		6-10
	c. Property Taxes		6-10
	d. State and Federal Income Tax		6-10
	e. Depreciation Expense		6-12
	f. Return on Rate Base		6-12
	g. Megawatts Installed		6-12
	h. Average $/MW		6-12
	i. PV UOG Program Rate Base		6-12
	(1) Plant		6-13
	(2) Accumulated Deferred Taxes		6-13
	(3) Accumulated Deferred ITC		6-13
	(4) Accumulated Depreciation		6-13
	(5) Capital Expenditures		6-14
	3. Revenue Requirement for PV Pilot Project		6-14
	4. Revenue Requirement for Land Deposits		6-16
	D. Levelized Cost of Energy for PV UOG Program		6-17
	E. Conclusion		6-17
Appendix A	STATEMENTS OF QUALIFICATIONS	Doug Herman Garrett P. Jeung Michael L. Jones Brian M. McDonald Joseph F. O'Flanagan Fong Wan	

PACIFIC GAS AND ELECTRIC COMPANY

CHAPTER 1

POLICY CHAPTER: EXECUTIVE SUMMARY AND OVERVIEW OF APPLICATION

PACIFIC GAS AND ELECTRIC COMPANY
CHAPTER 1
POLICY CHAPTER: EXECUTIVE SUMMARY AND OVERVIEW OF APPLICATION

TABLE OF CONTENTS

A. Introduction 1-1

B. Program Overview 1-2

1. PV UOG Program 1-2

2. PV PPA Program 1-3

3. PV Pilot Project 1-4

C. Rationale for the PV Program 1-5

1. The PV Program Supports California and Federal Environmental Goals 1-5

2. Utility Ownership of PV, Coupled With a Similar PPA Program, Is Appropriate and Beneficial for Customers 1-6

D. Testimony Overview 1-8

E. Conclusion 1-9

PACIFIC GAS AND ELECTRIC COMPANY
CHAPTER 1
POLICY CHAPTER: EXECUTIVE SUMMARY AND OVERVIEW OF APPLICATION

A. Introduction

This chapter provides an overview of Pacific Gas and Electric Company's (PG&E or the Company) Application for approval of an up to 500 megawatt (MW) Photovoltaic Program (PV Program) and discusses the rationale for and the policy objectives advanced by the PV Program.

PG&E proposes to initiate by January 2010, a multi-year program to develop up to 500 MW[1] of dispersed, mid-sized (typically 1 to 20 MW) photovoltaic generation installations in PG&E's service territory in northern and central California. The PV Program will consist of up to 250 MW of Utility-Owned Generation (UOG), with an anticipated capital cost of up to $1.45 billion, and up to 250 MW of Power Purchase Agreements (PPA) with third party renewable resource developers, with both programs anticipated to be developed over a 5-year period. PG&E will also build an up to 2 MW PV Pilot Project starting in 2009, to speed deployment of the larger PV Program, once it is approved.

A unique feature of this PV Program is that the pricing for the PPAs will be derived from the cost-of-service of the UOG projects. Under PG&E's PV Program proposal, the terms and conditions and the pricing of the PPAs will be pre-approved by the California Public Utilities Commission (CPUC or Commission), thus enabling a developer to execute the form contract with streamlined regulatory review, avoid the need for negotiations, and immediately commence development of its project.

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[1] Unless otherwise specified, references to capacity targets and overall program design in this filing are presented as alternating current (AC). PV unit cost estimates, on the other hand, are presented in terms of $/unit of direct current (DC) output as PV panels are usually priced in DC. PG&E relies on a conversion factor of 0.82 to convert from MW (DC) to MW (AC). Based on this conversion factor, PG&E's 250 MW (AC) PV UOG Program equates to the development of up to 305 MW (DC).

PG&E selected the PV technology proposed in this Application for a number of reasons: (1) PV is a proven and commercially ready technology; (2) northern and central California contain a number of regions with good insolation suitable for PV deployment; (3) PV is modular and can be rapidly deployed starting in 2010, and thereafter, helping to meet the 2010 Renewable Portfolio Standard (RPS) target (under flexible compliance); (4) mid-size PV projects will facilitate an expedited interconnection process; and (5) solar technology addresses PG&E's peak load demands.

A key objective of the PV Program is to expedite and simplify the regulatory approval process and to facilitate the systematic development of PV resources. The PV Program will provide a timely economic stimulus to the suddenly struggling PV industry, send strong signals to PV manufacturers to invest in and expand their manufacturing capability, and provide the foundation for driving PV costs down through efficiency gains expected to result from continuous investment and development experience. The PV Program also fits with PG&E's goal to demonstrate environmental leadership.

B. Program Overview

1. PV UOG Program

As described in Chapter 2, the UOG portion of the PV Program targets development of up to 250 MW of PV generation. Each project will generally be between 1 and 20 MW in size and connected to PG&E's electricity grid. Projects will be primarily ground-mounted, although some projects will potentially be rooftop-mounted. PG&E anticipates developing 25 MW in 2010, 50 MW each in 2011, 2012 and 2013, and 75 MW in 2014, although the actual amount of annual development may vary. PG&E may pursue projects below 1 MW where opportunities exist that complement rather than compete with the California Solar Initiative (CSI), and requests explicit authority to develop projects of any size below 20 MW. PG&E does not anticipate that projects below the 1 MW size would constitute a significant portion of the PV UOG Program.

All UOG projects will be located within PG&E's service territory. Where feasible, PG&E will work to develop projects on utility-owned land that is at

or near its existing substations, in addition to targeting regions of PG&E's service territory that are transmission constrained, where feasible.

PG&E will use a competitive procurement process to secure the lowest possible costs for the PV UOG Program. PG&E's solicitation will consider both bundled turnkey (engineering, procurement and construction (EPC)) bids and unbundled EPC bids (where PG&E could supply owner-furnished major equipment to a construction/installation contractor). In 2009, PG&E will issue a PV UOG Program competitive solicitation concurrent with regulatory review of the PV Program, providing for expedited program implementation once CPUC review is complete. Acceptance of bids will be contingent on CPUC approval of this Application.

As described in Chapter 6, PG&E proposes that the Commission approve annual capacity price targets for the UOG portion of the PV Program. These price targets, plus a contingency, will establish a regulatory benchmark that will be tracked over the life of the Program. At the end of the Program, PG&E will true-up its actual costs to the benchmark. If actual installed capacity costs are at or below the target, no additional reasonableness review would be required. If actual installed capacity costs are in excess of the target, PG&E would retain the opportunity to file an application to recover the excess amounts, subject to a reasonableness review of those excess amounts. If PG&E determines it cannot meet the regulatory benchmark or external economic factors (*e.g.*, the financial market crisis) limit the prudent and economic use of capital, PG&E reserves the right to suspend or scale back the Program.

PG&E anticipates securing some land, via deposits, ahead of CPUC approval of the PV Program. This land, supplemented by utility-owned land, will allow PG&E to begin the detailed and site-specific development work to ensure timely online dates for the future PV facilities.

2. PV PPA Program

The PPA portion of the PV Program has been designed to minimize the time for regulatory review and transaction negotiation, and to spur development of PV facilities by third party renewable developers. To be eligible for the PV PPA Program, the project size must be from 1 to 20 MW, and located in PG&E's service territory. As described in Chapter 3, PG&E

has requested that the CPUC adopt a standard form of contract, including an up-front, non-negotiable standard price derived from the PV UOG Program cost. The standard contract will be closely modeled after PG&E's standard contract proposal submitted with its 2009 RPS Plan.[2] Thus, the PV PPA Program proposal, once approved by the CPUC, streamlines the regulatory review of individual transactions because the price and terms will be pre-approved.

The anticipated size of the PV PPA Program is up to 250 MW, which is consistent with the size of the PV UOG Program. The PV PPA Program will be implemented over the 5-year life of the Program, although the exact annual allocation will be determined by the strength of the submissions to the annual Requests for Offers (RFO). If the solicitation is undersubscribed, the remaining MWs will roll over to future solicitations. If the PPA RFO is oversubscribed, PG&E will favor PV projects that are highly viable (*e.g.*, site control and online date) and provide the most energy value (*e.g.*, delivery time). PG&E anticipates that it will issue the first PPA RFO in early 2010, shortly after CPUC approval of the PV Program. Based on this RFO, PG&E expects to award approximately 50 MW of contracts in the second or third quarter of 2010. PG&E will hold an annual PPA RFO each year thereafter until the up to 250 MW is filled, although any remaining RFOs for the PV PPA Program will be eliminated if the PV UOG Program is terminated for any reason.

The standard contract will require the winning PV projects to be online within 18 months after execution of the PPA. Pricing for the PPAs will be based on PG&E's expected levelized cost of energy for the PV UOG Program, which should equate to $246/megawatt-hour (MWh), and which will be adjusted by time-of-day (TOD) factors.

3. PV Pilot Project

As described in Chapter 2, PG&E intends to proceed with the development of an up to 2 MW PV Pilot Project in 2009, prior to regulatory approval of this Application. Cost recovery for the Pilot is requested in this

[2] PG&E 2009 Renewable Energy Procurement Plan (R.08-08-009), filed September 15, 2008; pp. 33-35 and Appendix C.

Application, which would provide capacity in addition to the overall up to 250 MW PV UOG Program. The capital cost of the PV Pilot Program is expected to be $11.9 million.

The up to 2 MW Pilot will likely be located on existing utility-owned land. The purpose of the Pilot is to expedite the deployment of the PV Program, demonstrate PG&E's commitment to the PV Program, and to allow PG&E to develop and refine internal and external processes needed to develop, permit, construct, and operate a PV facility prior to deployment of the larger PV Program.

C. Rationale for the PV Program

1. The PV Program Supports California and Federal Environmental Goals

As the CPUC is well aware, the RPS Program requires utilities in California to attain and maintain a renewable resource portfolio equal to 20 percent of their retail load by 2010, or 2013 with flexible compliance. In addition, California is actively considering increasing its renewable goals beyond the current 20 percent renewable energy target. Governor Schwarzenegger's Executive Order issued in November 2008, describes a new target for California of 33 percent renewable energy by 2020.[3] The California Legislature is actively considering legislation increasing the overall RPS target to 33 percent.[4] The California Air Resource Board's (CARB) Scoping plan, adopted in December 2008, also indentifies an increase in the renewables target to 33 percent by 2020, as a key measure for reducing greenhouse gas emissions and meeting California's climate change goals.[5]

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[3] Executive Order S-14-08, signed November 17, 2008; http://gov.ca.gov/index.php?/press-release/11073/.

[4] Assembly Bill (AB) 64 and Senate Bill 14 currently consider increases to California's renewable portfolio standard to 35 percent and 33 percent, respectively:

SB14 http://www.leginfo.ca.gov/pub/09-10/bill/sen/sb_0001-0050/sb_14_bill_20090129_amended_sen_v98.html.

AB64 http://www.leginfo.ca.gov/pub/09-10/bill/asm/ab_0051-0100/ab_64_bill_20081209_introduced.html.

[5] CARB Scoping Plan, pp. ES-3.

The PV Program is designed to rapidly increase renewable resource energy deliveries in order to help meet the 2010 RPS goal under flexible compliance. The PV UOG Program is anticipated to add up to 0.5 percent to renewable energy sales by 2013, add up to 0.7 percent by 2014 when the PV UOG Program is fully deployed, and add up to 1.3 percent when the entire PV Program, including PPAs, is fully built. California leads the nation in its targets for renewable energy, but many risks and obstacles remain that may jeopardize the state's ability to meet this goal. The PV Program diversifies California's renewable portfolio by adding utility ownership and emphasizing mid-sized (1 to 20 MW) PV projects for PPAs.

The PV Program will also further the goals of California's 2006 Global Warming Solutions Act (AB 32), which seeks to reduce California's greenhouse gas emissions through an initial goal of returning economy wide emissions back to 1990 levels by 2020. Finally, the PV Program will also support the federal energy and environmental policy objectives outlined in President Obama's energy plan and detailed in several drafts of federal House and Senate legislation that call for aggressive action to reduce greenhouse gas emissions over the next 10 to 40 years.[6]

2. Utility Ownership of PV, Coupled With a Similar PPA Program, Is Appropriate and Beneficial for Customers

Solar PV is, in many respects, at a crossroads. The PV industry has the potential to continue to grow or to stagnate. PV technology is proven and efficiency gains are being realized every year.[7] Until the recent financial downturn, the industry was increasing production, driving down costs, and expanding manufacturing. PG&E has signed a number of PPAs for large-scale PV facilities, as well as some smaller contracts for promising

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[6] President Obama's "New Energy for America" plan proposes that 10 percent of our electricity comes from renewable sources by 2012, and 25 percent by 2025; and recommends an economy-wide cap-and-trade program to reduce greenhouse gas (GHG) emissions 80 percent by 2050. http://www.whitehouse.gov/agenda/energy_and_environment/.

[7] National Renewable Energy Lab's National Center for Photovoltaics publishes a chart that depicts "Best Research – Cell Efficiency" demonstrating a steady improvement across a variety of materials in efficiency of photovoltaics since 1975. http://www.nrel.gov/pv/thin_film/docs/kaz_best_research_cells.ppt.

innovative variations to the technology. As bright as this future seems, the industry is threatened by the financial market crisis, delays associated with obtaining development permits, and completion of transmission upgrades and interconnections needed to interconnect large projects. Independent developers are facing challenges in funding projects due to: (1) a reduced number of large institutions willing to invest tax equity; (2) reduced availability of credit for asset-based project financing; and (3) higher required rates of return for those who can raise the necessary equity and debt capital.[8] The PV Program will provide a needed economic stimulus for the PV industry in California.

First and foremost, PV is a good technology for California because: California is fortunate to have significant solar resources; there are a number of regions in northern and central California with excellent insolation and many others with good insolation that can support PV; solar technology fits well with PG&E's portfolio; and solar technology produces energy when it is warm and sunny, and matches PG&E's peak-load energy demands.

Second, PV can be deployed rapidly starting in 2010, and each year thereafter, to help meet the 2010 RPS goal (under flexible compliance). By targeting medium scale projects specifically designed to avoid the interconnection and transmission barriers confronting other larger projects, the PV Program will facilitate an expedited connection process. The target size of primarily 1 to 20 MW for the proposed projects also complements other programs such as the CSI Program and feed-in tariff that support small projects (less than 1 MW or 1.5 MW, respectively).

Third, utility ownership of PV projects bypasses the financial challenges confronting renewable development today. PG&E is highly likely to be capable of financing the UOG portion of the PV Program. PG&E also has a sufficient tax obligation to make full use of the tax incentives now available to utility-owned renewable projects. These tax incentives were extended to

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[8] A recent article in the *New York Times*, "Dark Days for Green Energy," reported on the significant impact of financial and economic crises on renewable development; February 4, 2009. http://www.nytimes.com/2009/02/04/business/04windsolar.html?partner=permalink&exprod=permalink.

utilities by recent federal legislation and provide the investment tax credit (ITC) to reduce the cost of utility-owned renewable generation.

Fourth, for several years, the CPUC has actively encouraged utility ownership of renewable resources. In decisions approving PG&E's 2006, 2007 and 2008 RPS Plans, the Commission emphasized the importance of an aggressive renewable strategy, part of which would involve utility ownership of new renewable resources.[9] More recently, in the 2006 Long-Term Procurement Plan (LTPP) proceeding, the Commission authorized utilities to propose ownership of renewable facilities outside of an RFO.[10]

Finally, new utility-owned renewable generation will provide a greater level of transparency for PG&E and the CPUC on the cost of renewable development that cannot be obtained through the RPS contracting process with an independent power producer.

Renewable projects developed by independent power producers are a critical part of PG&E's overall effort to meet its RPS goals and will remain so. The current financial market turmoil and economic slowdown, coupled with the tax credits only just now made available for utility renewables investment, warrants PG&E diversifying its portfolio of renewable resources by adding UOG.

D. Testimony Overview

The remaining chapters of this testimony provide additional detail to support the PV Program. The remaining chapters are organized as follows:

- Chapter 2: Photovoltaic Utility-Owned Generation Program;
- Chapter 3: Photovoltaic Power Purchase Agreement Program;
- Chapter 4: Capital Costs;
- Chapter 5: Operations and Maintenance Costs; and
- Chapter 6: Revenue Requirement and Ratemaking for PG&E's Photovoltaic Program.

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[9] D.06-05-039 at p. 34; D.07-02-011 at p. 24; D.08-02-008 at p. 32.

[10] D.07-12-052 at p. 211; D.08-11-008 at p. 21.

E. Conclusion

PG&E's PV Program proposes up to 500 MW of development of mid-sized (typically 1 to 20 MW) PV projects over five years, split between UOG and standard contract PPAs. The PV Program will also include an up to 2 MW pilot project designed to aid rapid deployment of the PV Program once regulatory review is complete by the end of 2009. PG&E's PV Program supports California's environmental goals, is the appropriate technology, and is beneficial for customers.

PACIFIC GAS AND ELECTRIC COMPANY

CHAPTER 2

PHOTOVOLTAIC UTILITY-OWNED GENERATION PROGRAM

PACIFIC GAS AND ELECTRIC COMPANY
CHAPTER 2
PHOTOVOLTAIC UTILITY-OWNED GENERATION PROGRAM

TABLE OF CONTENTS

A. Introduction 2-1

B. Outline of Program 2-1

C. Size 2-2

D. Timing 2-2

E. Location 2-3

F. Technology 2-4

G. Interconnection 2-5

H. Implementation 2-6

I. Conclusion 2-7

PACIFIC GAS AND ELECTRIC COMPANY
CHAPTER 2
PHOTOVOLTAIC UTILITY-OWNED GENERATION PROGRAM

A. Introduction

The purpose of this chapter is to describe the Utility-Owned Generation (UOG) portion of Pacific Gas and Electric Company's (PG&E or the Company) proposed photovoltaic program (PV Program). Specifically, this chapter provides an overall outline for this part of the PV Program, its anticipated timing, its size, the expected deployment locations, types of technology being examined, and the implementation plan. This section covers only the UOG portion of the PV Program, with the Power Purchase Agreement (PPA) portion covered separately in Chapter 3.

B. Outline of Program

The UOG portion of the PV Program targets development of up to 250 megawatts (MW) of utility-owned PV-based generation with projects typically ranging in size from 1 to 20 MW.[1] Projects will be primarily ground-mounted PV installation, though PG&E may deploy some roof-mounted systems. The systems will be connected to PG&E's grid. As described in more detail below, the typical 1 to 20 MW size should allow PG&E to bring these projects online faster and begin delivering renewable solar power to customers sooner than larger-scale PV installations. All UOG projects will be located within PG&E's service territory. Where possible, PG&E will work to develop projects on utility-owned land in order to further lower costs and better control project deployment.

PG&E will bring projects online at 50 MW per year on average, with the first projects coming online in 2010. However, project timelines could be affected if regulatory approval is significantly delayed beyond 2009.

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[1] Unless otherwise specified, references to capacity targets and overall program design in this filing are presented as alternating current (AC). PV unit cost estimates, on the other hand, are presented in terms of $/unit of direct current (DC) output as PV panels are usually priced in DC. PG&E relies on a conversion factor of 0.82 to convert from MW DC to MW AC. Based on this conversion factor, PG&E's 250 MW AC PV UOG Program equates to the development of up to 305 MW DC.

As described in Chapter 6, PG&E has estimated the total cost of the PV UOG Program to be approximately $1.45 billion.

C. Size

PG&E plans to develop up to 250 MW of UOG, with an average of 50 MW deployed annually. A total scale of 250 MW represents approximately 0.7 percent of PG&E's retail load. PG&E anticipates enough units to be online by 2013 to supply approximately 0.5 percent of load, which will count toward PG&E's 2010 Renewable Portfolio Standard (RPS) target under flexible compliance. At the same time, the 50 MW a year average size provides a manageable scale for annual deployment. This would represent 3 to 50 projects annually (depending on each project's size). PG&E believes this is a manageable project load and that it will be successful in bringing projects online in the timeline contemplated.

The PV UOG Program will target projects typically sized from 1 to 20 MW. This size range has been selected for two key reasons. First, projects at this scale are too large to qualify for incentives under the California Solar Initiative (CSI) program. Second, projects at this scale allow for an accelerated time to market. These projects can be constructed in a matter of months, rather than years when compared to larger projects. Furthermore, projects at this scale are not required to participate in the California Independent System Operator's (CAISO) Large Generator Interconnection Procedures (LGIP), which should allow these projects to come online quicker. These factors, combined together, make this size range a logical scale for the PV UOG Program to target. PG&E may also pursue the development of some smaller scale projects under 1 MW where opportunities exist that complement the CSI.

D. Timing

PG&E proposes to roll out the PV UOG Program over five years between 2010 and 2014. After anticipated CPUC approval by the end of 2009, PG&E plans to bring approximately 25 MW of new PV capacity online in 2010. For 2011 through 2013, PG&E is targeting approximately 50 MW of new PV capacity additions annually, with approximately 75 MW brought online in 2014. PG&E's actual rate of annual deployment may vary from these estimates depending on factors such as financial market conditions, site availability, equipment

availability and permitting. PG&E may either accelerate deployment to bring more generating capacity online sooner, or slow or suspend deployment if market conditions make deployment unfeasible. PG&E would not exceed the PV Program total of 250 MW without seeking California Public Utilities Commission (CPUC or Commission) approval to expand the program.

PG&E anticipates taking some action ahead of CPUC approval, including developing a PV Pilot Project, securing land, and conducting a competitive process to secure equipment and construction services.

PG&E will develop, construct and operate an up to 2 MW PV Pilot Project. Developing this plant ahead of CPUC approval will allow PG&E to establish internal mechanisms to ensure an effective deployment of the PV UOG Program and will provide practical, hands-on experience. The PV Pilot Project will also ensure that once the Program is approved, PG&E is better able to efficiently develop and construct multiple facilities.

Similarly, PG&E anticipates securing some land, via deposits, ahead of CPUC approval of the PV Program. This land, supplemented by PG&E utility-owned land, will allow PG&E to begin the detailed and site-specific development work to ensure timely online dates for the future PV facilities.

Finally, PG&E will solicit competitive bids in 2009, in order to execute its proposed implementation plan described later in this chapter.

E. Location

The PV UOG Program will be limited to developing facilities within PG&E's service territory. This limitation will ensure that PG&E can provide maintenance and support to these sites economically and assists with keeping the overall project costs down.

Most projects will be located near PG&E substations to minimize the cost of interconnecting to PG&E's grid, though roof-mounted projects would have more flexibility. Where feasible, PG&E will develop projects on PG&E utility-owned properties. This option can be more economical than developing projects on third-party sites where the cost of securing land would increase the delivered cost of energy for the project. The location of any specific facility will be determined based on least cost, best fit. This means that PG&E will examine multiple location factors (listed below) and balance them to achieve the greatest value for our customers. For example, PG&E may choose a location with more

expensive land because a lower interconnection cost provides a more economical project. The criteria for site selection are listed below:

- **Insolation:** The quality of the solar resources in a specific site, which partially determines the amount of energy a site can generate annually;
- **Slope:** Flat, level, or gently sloped locations are less costly to construct on and operate;
- **Cost of Interconnection:** Sites that provide lower cost interconnections will lower the overall cost of the project.
- **Capacity Available at the Substation:** Substations that have a greater ability to accept power will allow PG&E to build larger individual plants, which are likely to come at a lower cost per kilowatt (kW);
- **Availability and Cost of Sites:** Locations with lower cost of land in large areas will lower overall project costs. PV facilities generally require 7 to 10 acres per MW of capacity;
- **Minimal Environmental Impact:** Minimizing environmental impact fits with PG&E's and its customers values. It also minimizes development costs and reduces uncertainty; and
- **Local Transmission Constraints:** Placing projects in locations with local transmission constraints can create additional value for customers.

F. Technology

PG&E has not selected a single technology for the PV UOG Program, but instead plans to select the best technology based on the results of its competitive solicitation. The current PV technologies all have various trade-offs, including: panel cost, panel efficiency, peak performance in direct sunlight, best average performance during an entire day, best diffuse light performance (performance on a cloudy day), reliability, and maintenance requirements. PG&E will weigh these different attributes to select the technology that provides the best value for its customers.

The two main categories of PV technology in the market today are crystalline silicon solar cells and thin-film solar cells. Crystalline silicon solar cells make up the majority of the market today and have the longest operating history. They come in two forms: monocrystalline and polycrystalline. The

crystalline technology has evolved from the semiconductor industry and crystalline cells tend to have higher efficiency than thin-film solar cells, thereby requiring less space to produce the same total output. However, the historic disadvantage of crystalline cells is that they tend to be expensive.

An alternative technology is thin-film solar cells. These cells are made by depositing a thin layer of semiconductor material to a substrate (for example, coated glass). The deposited material can be amorphous silicon (still silicon as used in crystalline cells, but in a different form) or a polycrystalline material such as cadmium telluride. Thin-film cells use very thin layers of material, thereby reducing material costs and reducing the overall cost of the cells. However, thin-film cells also tend to be less efficient than traditional crystalline cells, meaning more cells and more space are required to produce the same amount of energy.

Beyond the PV panels, a complete system requires inverters, racks, and wiring. The power generated by PV panels, no matter the technology, is DC. In order to be fed into the power grid, this must be converted to AC by the inverter. Similarly, racks are required to hold and position the panels and wiring is required to connect all of the panels together into a complete system.

As stated earlier, PG&E does not have a technology preference for its utility-owned projects. PG&E will weigh panel cost, efficiency, cost of construction, maintenance costs, total power output, and other attributes to select the technology that is the best and most economic fit for our customers.

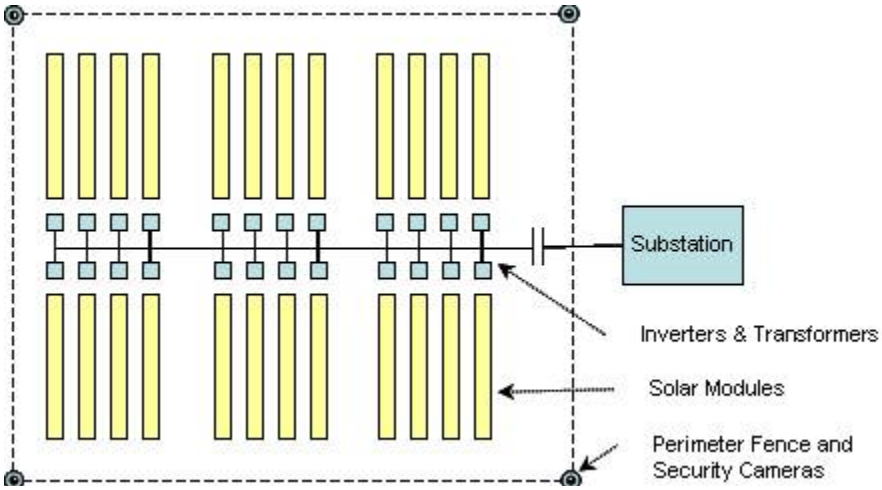
G. Interconnection

PG&E proposes using the Federal Energy Regulatory Commission (FERC)-approved Small Generator Interconnection Procedures (SGIP) to ensure a non-discriminatory interconnection process for PG&E's UOG facilities. While the focus or expectation of these programs is on distribution voltage interconnections (below 50 kilovolt (kV), typically 12 kV and 21 kV), the SGIP does provide for transmission interconnections as well, as long as the capacity is no greater than 20 MW per generation facility. While PG&E anticipates that the majority of facilities will be interconnected at the distribution voltage level, it may be that in some circumstances, a transmission level interconnection is more appropriate. The pre-application process outlined in Section 1.2 of the SGIP provides an opportunity for the Distribution Provider and the Interconnection

Customer to gain clarity on whether the Interconnection Request (Application) to the Distribution Provider should be at the distribution or transmission voltage level.

There are a range of interconnection options that PG&E will use for its PV UOG Program. The type of facilities required to interconnect PV projects to substations will vary depending on the interconnection configuration required for each project. In general, PV modules will be connected to inverters, which will then be connected to step-up transformers, which will be connected to the power grid. These general interconnection facilities are depicted graphically below in Figure 2-1. However, the precise facilities that will be required and the cost of interconnection will vary significantly depending on the type of configuration required to connect each facility.

FIGURE 2-1
PACIFIC GAS AND ELECTRIC COMPANY
SAMPLE PV FACILITY LAYOUT



H. Implementation

To leverage its resources and obtain cost competitive facilities, PG&E will use a small construction management team to manage contractors implementing the engineering, procurement, construction, and commissioning of the PV facilities. PG&E will structure its solicitation method to maximize competitive pricing, volume discounts, and price certainty that will provide the most cost-effective systems. PG&E's solicitation will consider both bundled turnkey (engineering, procurement and construction (EPC)) bids and unbundled

EPC bids (where PG&E could supply owner-furnished major equipment to a construction installation contractor).

I. Conclusion

This section of testimony provides a summary of the UOG portion of the PV Program. The timing, scale, location, implementation, and technology choices described in this section should be combined with the capital cost estimates in Chapter 4 and the Operating and Maintenance (O&M) costs in Chapter 5 to provide a complete understanding of the UOG portion of the PV Program.

PACIFIC GAS AND ELECTRIC COMPANY

CHAPTER 3

PHOTOVOLTAIC POWER PURCHASE AGREEMENT PROGRAM

PACIFIC GAS AND ELECTRIC COMPANY
CHAPTER 3
PHOTOVOLTAIC POWER PURCHASE AGREEMENT PROGRAM

TABLE OF CONTENTS

A. Introduction 3-1

B. Outline of Program 3-1

C. Timing and Timeline 3-2

D. Eligibility 3-2

1. Technology 3-3

2. Project Size 3-3

3. New Projects 3-3

4. Location of Generating Facility 3-4

E. RFO Selection Process 3-4

1. Project Viability 3-4

2. Market Valuation 3-5

3. Credit 3-5

4. RPS Goals 3-5

F. General Contract Terms 3-5

G. Pricing 3-8

H. Regulatory Approval 3-8

I. Conclusion 3-8

PACIFIC GAS AND ELECTRIC COMPANY
CHAPTER 3
PHOTOVOLTAIC POWER PURCHASE AGREEMENT PROGRAM

A. Introduction

The purpose of this chapter is to describe the Power Purchase Agreement (PPA) portion of Pacific Gas and Electric Company's (PG&E or the Company) proposed Photovoltaic (PV) Program. Specifically, this chapter will provide an overall outline for this part of the PV Program, its anticipated timing, its size, eligibility requirements, project selection and pricing and key terms.

B. Outline of Program

The PPA portion of the PV Program is designed to target development of up to 250 MW of seller-owned photovoltaic-based generation. Through PG&E's PV PPA Program, independent power producers (IPPs) will be offered an opportunity to provide PG&E with similar generation capacity compared to the PV Utility-Owned Generation (UOG) Program megawatts (MW). PG&E will contract with sellers for up to 250 MW of PV generation over five years at a price comparable to the utility cost-of-service. PG&E will conduct annual Requests for Offers (RFO) for PPAs and select up to 50 MW per year. Winning bidders will sign a standard, 20-year, fixed-price contract that includes appropriate terms and conditions to induce the seller to develop and deliver renewable energy to PG&E by the contractual online date and over the contract term. The PV PPA Program RFO protocol and standard contract will be modeled after the then-current California Public Utilities Commission (CPUC or Commission) approved PG&E Renewable Portfolio Standard (RPS) RFO protocol and standard form contract. In this case the current protocol and standard contract are those filed with PG&E's 2009 RPS Plan.[1] The first PV PPA Program RFO would be conducted in early 2010, after regulatory approval of the PV Program. The contracts would be targeted for award in the summer of 2010, with project online dates within 18 months of the contracts being effective. PG&E will conduct

[1] PG&E 2009 Renewable Energy Procurement Plan (R.08-08-009) filed September 15, 2008.

annual RFOs thereafter, although any remaining RFOs for the PV PPA Program will be eliminated if the PV UOG Program is terminated for any reason.

Each project will be between 1 MW and 20 MW in size. As with the PV UOG Program, these mid-sized projects should allow the IPPs to bring these projects online quickly and begin delivering renewable solar power to PG&E's customers expeditiously. All projects must be located within PG&E's service territory.

C. Timing and Timeline

PG&E will hold annual RFOs (up to 50 MW each) from 2010 to 2014. The first PV PPA RFO will be held in early 2010, and will seek projects with online dates by the end of 2011. Each subsequent PV PPA RFO will solicit projects that would be online within 18 months after the contracts become effective, with anticipated project online dates by the end of 2012, 2013, 2014 and 2015. If PG&E does not award a total of 50 MW in a given RFO, the unallocated megawatts will be rolled over into the following year's PV PPA RFO. The schedule below illustrates the timing for the first PV PPA RFO. This schedule could change if the CPUC approval is delayed beyond 2009.

TABLE 3-1
PACIFIC GAS AND ELECTRIC COMPANY
PV PPA RFO SCHEDULE

Line No.		
1	End of 2009	CPUC Approval of PV Program.
2	January 2010	PG&E Updates/Finalizes PPA Documents and Solicitation Protocol Consistent with CPUC Decision.
3	February 2010	PG&E Issues PV PPA RFO.
4	March 2010	Bids Due in PV PPA RFO.
5	June 2010	Winning Bidders Selected.
6	July 2010	PPA Contracts Approved by CPUC via Tier 1 Advice Letter.
7	December 2011	Deadline for PV Projects to be Online.

D. Eligibility

In order to participate in the PV PPA RFO, sellers must meet the following eligibility requirements:

1. Technology

To qualify as eligible for the PV PPA RFO, a generation facility must use photovoltaic technology, as defined by the current version of the applicable California Energy Commission (CEC) Guidebooks.[2] PG&E has not selected a single PV technology for its PV PPA Program, but instead may select multiple technologies based on the results of its RFO. Photovoltaic technology is rapidly evolving. The best cost/performance choice today may not be the best cost/performance choice a couple years from now as the technology continues to evolve and new companies enter the market. This is one of the key reasons for holding annual PV PPA RFOs. There may be cost-effective technologies that can participate in later PV PPA RFOs that do not exist today.

2. Project Size

For the PV PPA RFO, the minimum size for eligible projects to bid into the competitive solicitation is 1 MW, with a maximum size of 20 MW. This size range has been selected for two key reasons. First, the 1 MW minimum provides an opportunity for projects that exceed the 1 MW maximum eligibility for net metering and the California Solar Initiative (CSI) Program incentive. Second, projects at this scale (and under 20 MW) can be constructed relatively quickly. As described in Chapter 2, projects at this scale are not required to participate in the California Independent System Operator's (CAISO) Large Generator Interconnection Procedures (LGIP), allowing projects to come online more quickly. These factors make this size range a logical scale for the PV PPA Program to target.

3. New Projects

In order to ensure that the PV PPA Program increases the total supply of renewable generation, PG&E will consider only new PV generating facilities in the PV PPA RFO. Existing projects have other options to contract with PG&E, depending on their size. Projects greater than 1.5 MW may bid into PG&E's annual RPS solicitation or enter into a bilateral

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[2] CEC Renewables Portfolio Standard Eligibility, Third Edition, Adopted December 19, 2007.

negotiation with PG&E. Projects less than 1.5 MW may sell all or excess generation to PG&E under a standard contract form.

4. Location of Generating Facility

Consistent with the UOG portion of the PV Program, projects must be located in PG&E's service territory.

E. RFO Selection Process

The PV PPA RFO will be modeled on the successful RPS RFOs that PG&E has conducted since the RPS program began in 2002. As with the RPS RFOs, the PV PPA RFO will be conducted according to a published protocol, under the supervision of an Independent Evaluator. The 2010 PV PPA RFO will be based on the 2009 RPS Plan and Protocol, which includes a standard contract, subject to modifications or changes that may be made by the Commission to the 2009 Protocol or standard contract. After the 2009 RPS Plan and Protocol are adopted by the CPUC, PG&E will submit the approved 2009 protocol and standard contract, with any necessary changes for this program, through a compliance filing in this proceeding. PG&E will update its standard contracts for future solicitations as needed to reflect changes in law, CPUC decisions or changed market conditions.

PG&E will award up to 50 MW of PV in each annual RFO. The evaluation process used by PG&E will be similar to the process used in the RPS RFO evaluation. The primary difference is that in the PV PPA RFO bidders do not bid a price—the price is set for all bidders before the RFO. Thus, a key distinction between offers will be the viability of the project. PG&E will select those projects that are most likely to be brought online and deliver energy as promised. The following describes the CPUC approved RPS evaluation criteria and how they will be applied to the PV PPA RFO bids.

1. Project Viability

Project viability is a critical factor in the selection process. Project viability addresses the project status, the project site, and the experience and qualification of the project developer. Project status is assessed by the developmental stage and the likelihood of the project's ability to obtain permits. Since projects must be online within 18 months of a contract being effective, those projects in advanced development (e.g., permits received,

equipment purchased, sites and easements obtained, transmission studies completed (if necessary) and status of design/construction) will be preferred to those in earlier stages of development. Resource risk will be assessed on whether resource availability and sustainability have been proven in the project location. Bidder experience will be assessed on whether the bidder has experience with the specific technology offered or whether the bidder has experience with other renewable or conventional power generation. Long run viability is also important and takes into account an assessment of the technology as it relates to continued project reliability. PG&E will incorporate other potential changes to viability assessment, including seller concentration once they are adopted by the CPUC for the 2009 RPS Plan.

2. Market Valuation

Although winning bidders will be receiving the same price for their energy, and the deliveries will all be from PV projects, the market value, including local Resource Adequacy value, may differ due to delivery location and generation profile.

3. Credit

Credit is assessed by the bidder's ability to provide collateral to secure its obligations under the PPA. Credit requirements are standard and must be fully met for a project to be eligible.

4. RPS Goals

The PV PPA RFO evaluation will take into account the bidder's status as a Women, Minority and Disabled Veterans Business Enterprise (WMDVBE) and/or the bidder's intent or policy of subcontracting with WMDVBEs. PG&E's evaluation will also take into account whether the bidder has signed Project Labor Agreements and whether the bidder plans to pay prevailing wage.

F. General Contract Terms

All participants will be required to sign a standard, non-modifiable contract. Given the tight timeframes between the PV PPA solicitation, contract execution and commercial operation of the PV projects, there will be no negotiation of contract terms and conditions. The 2010 PV PPA will be based on the standard contract PPA from the 2009 RPS RFO that is adopted by the CPUC, as

discussed above. However, the PV PPA will include modifications to the RPS PPA to reflect the unique nature of the PV PPA Program. The changes required are limited in nature and reflect the fact that the PV PPA projects will be limited to PV technology and between 1 and 20 MW. Given the current draft of the 2009 RPS PPA, PG&E anticipates the following changes would be required to create a PV-only PPA:

- **Price and Term**: RPS PPA allows seller to specify price and term. PV PPA would mandate a fixed price and 20-year term.
- **Interconnection**: RPS PPA assumes seller will interconnect using LGIPs. PV PPA would delete references to LGIP and replace with SGIP.
- **Contract Delays**: RPS PPA allows for 18-month delay in construction start and online date associated with delays in transmission interconnection and transmission upgrade. Since smaller projects are expected to have shorter interconnection times, PV PPA would reduce allowance for transmission upgrade and interconnection delays from 18 months to 12 months and delete provisions for CAISO Limited Operations Studies, which are associated with LGIP. Consistent with the RPS PPA, the PV PPA would also allow for extension of online dates as a result of permitting delays or force majeure, as long as the cumulative delay associated with transmission, permitting and force majeure does not exceed 12 months.
- **Conditions Precedent**: RPS PPA is not effective and binding unless CPUC approval is received within 240 days. PV PPA would also be conditioned upon CPUC approval, but approval time would be substantially shorter given the Tier 1 Advice Letter process.

Key elements of the form PV PPA are summarized below. PG&E will update its PV PPA for future solicitations as needed to reflect changes in law, CPUC decisions or changed market conditions.

TABLE 3-2
PACIFIC GAS AND ELECTRIC COMPANY
PV PPA SUMMARY OF MAJOR TERMS AND CONDITIONS

Line No.		
1	Delivery Term	20 years.
2	Price	Based on UOG price. Payment is adjusted by Time of Delivery (TOD) factors. See Section G below.
3	Contract Quantity	Seller specifies annual delivery amount, which may decline over time to reflect PV degradation.
4	Online Date	Full capacity must be online within 18 months. It is anticipated that projects will be online by December 31, 2011 (based on the timing of the first RFO).
5	Performance Standards/ Requirements: Minimum production requirement.	In order to ensure that the Seller provides energy over the 20-year contract term, the PPA requires a minimum amount of energy, Guaranteed Energy Production (GEP) each year.
6	Scheduling	PG&E is Scheduling Coordinator (SC) for all projects.
7	Eligible Intermittent Resource Program (EIRP)	Generator is required to qualify and register for the EIRP for solar facilities, once the program is operational.
8	Metering	Required to have CAISO approved meter.
9	Imbalance Energy	For all resource types in the CAISO where PG&E is the SC, PG&E will assume Imbalance Energy risk. However, if Seller does not provide information required by the PPA, Seller bears the imbalance risk outside of a pre-determined tolerance band.
10	Guaranteed Milestones and other Key Limits	Seller specifies Guaranteed Construction Start Date (GCSD) and Guaranteed Commercial Operation Date (GCOD), which may be no longer than 18 months from when the contract becomes effective. Milestones may be extended up to one year due to cumulative delays in permitting, interconnection or force majeure.
11	Non-Performance or Termination Penalties and Default Provisions: Events of Default	Seller is subject to daily delay damages and contract default if project milestones are not met. Daily delay damages are assessed from and capped at project development security. This ensures that Seller has an incentive to bring project online as promised.
12	Credit Terms	The Seller must provide collateral during the project development period and delivery term: • Project development security: $50/kW upon CPUC approval; and • Delivery Term Security: Upon commercial operation, 12 months revenue.

G. Pricing

Consistent with standard renewable PPAs, Sellers will receive a contract price, adjusted by a TOD factor, for each megawatt-hour (MWh) produced. TOD factors will be the annual TOD factors adopted for the annual RPS solicitations.

The price for the PPAs to be awarded in the first RFO is set based on the average levelized cost of energy presented in Chapter 6. Chapter 6 shows a levelized annual cost of energy of $295/MWh. This translates to a pre-TOD contract price of approximately $246/MWh.[3]

For future PV PPA RFOs, PG&E recognizes the possibility that there could be significant technological improvements or efficiency gains which could result in substantial reductions to PV costs for the UOG projects. PG&E would expect to take advantage of these cost savings for customers for the UOG Program and would also want customers to be able to benefit from lower PPA costs. If PG&E determines that PV Program costs are substantially lower than forecast, based on experience with the PV Program or changed market conditions, PG&E will submit a revised PV PPA price through an advice letter, along with updated PPA forms, for CPUC approval prior to conducting subsequent annual PV PPA RFOs.

H. Regulatory Approval

The PV PPAs will have a pre-approved price and pre-approved terms and conditions. Thus, PG&E will file these agreements using a Tier 1 Advice Letter process. Under the Tier 1 process, approval of the advice letter is complete within 30 days unless the CPUC takes action otherwise. This streamlined approval process will allow developers a better chance to complete their projects, since the lag between contract execution (and commitment to a price and milestones) will be reduced.

I. Conclusion

This section of testimony provides a summary of the PPA portion of the PV program, detailing the timing, eligibility, RFO selection process, general contract terms, pricing and regulatory approval.

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[3] Given the expected generation profile of the PV facilities targeted by the PV Program, and PG&E's current TOD factors, expected revenues/MWh for a PV project would be 1.20 times contract price. Contract price × 1.2 = Levelized cost of energy.

PACIFIC GAS AND ELECTRIC COMPANY

CHAPTER 4

CAPITAL COSTS

PACIFIC GAS AND ELECTRIC COMPANY
CHAPTER 4
CAPITAL COSTS

TABLE OF CONTENTS

A. Introduction 4-1

B. Summary 4-1

C. Global Assumptions 4-3

D. PV System Contract Cost 4-4

E. Land Acquisition, Site Preparation and Permitting 4-4

F. Grid Interconnection 4-5

G. Security and SCADA 4-6

H. PG&E Supervisory Labor, Consulting Support, and Permits 4-6

I. Contingency 4-6

J. Pilot Project 4-6

K. Conclusion 4-7

PACIFIC GAS AND ELECTRIC COMPANY
CHAPTER 4
CAPITAL COSTS

A. Introduction

The purpose of this chapter is to set forth Pacific Gas and Electric's (PG&E or the Company) estimate of the capital costs necessary to construct 250 MW of the Utility-Owned Generation (UOG) portion of its Photovoltaic (PV) Program. PG&E currently intends to begin construction in 2010, assuming regulatory approval in late 2009.

B. Summary

In the summer of 2008, PG&E assembled vendor data and PG&E-supplied balance of plant components to arrive at an estimated total system cost (by year and on a weighted average), as presented in Table 4-1 below. PG&E collected indicative cost estimates from PV manufacturers and system integrators for PV panels, inverters, and complete systems. Discussions were held with a cross-section of established and emerging companies offering a variety of solar technologies, including crystalline silicon and thin-film panels, fixed and tracking mounts, and single-axis and dual-axis concentrating systems.

Vendors were asked to provide indicative pricing, technology specifications, and performance data for PV modules or turnkey systems for the following program design:

- 300 megawatts (MW) total program size, 75 MW per year deployment over four years, 2010-2013;[1]
- 2 MW or 5 MW project size;
- Flat, greenfield sites adjacent to PG&E substations;
- PG&E to provide sites, permitting, grid interconnection; and
- Prevailing wage labor.

[1] The program was subsequently changed up to 250 MW, with approximate deployments of up to 25, 50, 50, 50 and 75 MW per year. PG&E assumed that these changes would have negligible impact on the solar field cost per MW.

Technical data requested included:

- Technology descriptions;
- Physical weight and dimensions;
- Materials of construction;
- Performance ratings and curves showing the influence of varying ambient and cell temperatures and solar radiation levels;
- Degradation rates as a function of ambient and cell operating temperatures;
- Laboratory stress test data used to support lifetime performance claims;
- Field operating experiences, including deployment schedules by year of manufacture and location, associated failure and degradation rates; and
- Energy production at representative California locations (Bakersfield, Fresno, Daggett, Sacramento) using the 30-year average National Renewable Energy Laboratory (NREL) “Red Book” insolation and weather data set.

Commercial data requested included:

- Manufacturing capacities;
- Sales volumes;
- Warranty terms; and
- Operating and maintenance costs.

TABLE 4-1
CAPITAL COST ESTIMATE
PV UOG PROGRAM
$2009/KILOWAT (kW) DIRECT CURRENT (DC)(a)

Line No.	Program Cost Element	2010	2011	2012	2013	2014	Weighted Average
1	PV System Contract	3,605	3,334	3,108	2,943	2,884	3,103
2	Land Acquisition, Site Preparation and Permitting	270	268	265	262	259	264
3	Grid Interconnection	238	234	229	224	219	227
4	Security and SCADA	161	158	155	152	149	154
5	PG&E Supervisory Labor and Consulting	174	87	87	87	48	84
6	Subtotal	4,448	4,081	3,843	3,667	3,559	3,831
7	Contingency	499	470	445	427	419	444
8	Total Project Cost	4,947	4,551	4,288	4,094	3,979	4,275

(a) Costs are presented in year 2009 dollars.

As described in Chapter 2, PG&E intends to perform a competitive solicitation for the PV UOG Program. The costs presented above are the result of non-binding discussions with vendors.

C. Global Assumptions

In preparing the cost estimate used in this testimony, PG&E used the following global project assumptions:[2]

- 250 MW program, consisting of 25 MW deployment in 2010, 50 MW in 2011, 2012 and 2013 and 75 MW in 2014;
- 5 MW average project size per site;
- Ground mounted systems on flat, already disturbed agricultural land;
- Seismic Zone 4;
- Construction to local building regulations, codes and standards;
- 10 acres of land per MW of solar field;

[2] As discussed in Chapter 2, actual deployment, project sizes, and locations may vary from the assumptions used to develop the cost estimates.

- Annual performance degradation of 0.89 percent, which is consistent with a typical warranty of 80 percent output at 25 years of operating life;[3]
- Inverters replaced after 10 years of operation; and
- 25-year economic life with zero salvage value/disposal cost.[4]

D. PV System Contract Cost

The estimated PV System Contract cost, Table 4-1, line 1, is based on indicative price estimates provided by vendors, as mentioned above. The scope of the contract is bundled (turnkey), engineering design, equipment procurement, and construction (EPC). The system equipment includes panels, mounting racks or trackers, inverters and medium voltage field transformers, combiner boxes, fuse boxes and fuses, DC string wiring, alternating current (AC) system wiring to the interconnection switchyard, and a performance monitoring system. Construction costs are based on prevailing wage costs.

PG&E would provide the balance of system components: land and permitting; grid interconnection; site preparation; site security; and a System Control and Data Acquisition (SCADA) connection to the PG&E communication network.

E. Land Acquisition, Site Preparation and Permitting

The estimated land acquisition, permitting, and site preparation costs are indicated on line 2 of Table 4-1.

The estimated land cost is based on recent sales prices for Central Valley crop land, escalated at 2 percent per year, and with 10 acres required per MW. Given the need to develop land quickly, PG&E plans to use disturbed farmland, preferably of marginal agricultural quality. PG&E plans to use land having high insolation, as long as the price of the land and the grid interconnection costs are reasonable. PG&E also plans to use its own “buffer” land surrounding existing substations, to the extent that that land is not needed for future substation expansion and can be easily permitted. Use of existing land would result in

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[3] This assumption and the two below it affect annual energy production and operating costs, not the capital costs presented in Table 5-1.

[4] This is a conservative assumption in that the PV systems are expected to still be producing 80 percent of the original power output at the end of 25 years.

PV UOG Program cost savings, to the benefit of customers. As discussed earlier, PG&E may also deploy roof-mounted systems.

The land areas required to build solar fields make it important to use sites that require minimal preparation and that are suitable for low-cost foundations. PG&E conducted preliminary geotechnical surveys of 12 potential sites during the fall of 2008. The geotechnical surveys of these sites indicated that there were no major geotechnical or structural obstacles for PV development. Soil on the sites consisted of varying amounts of low-plasticity clay (CL), silty sand (SM) and clay sand (SC). This *mélange* of sand, soil, and silt is often termed "loam." None of the surveyed sites were in the Federal Energy Management Administration (FEMA) 100-year flood plain. This lack of inundation potential means there should be no *caliche* or significant amounts of cemented soil (which would prevent driving PV panel support columns). The potential for steel and concrete corrosion due to the soil can be mitigated with proper concrete mix designs and steel coatings (*e.g.*, galvanizing). The seismic hazard is generally low with slight increases for sites in the Bakersfield area and for sites closer to Interstate 5.

PG&E's Geosciences department estimated site preparation costs using best-judgment estimates for clearing minor vegetation, scarifying the upper 12 inches, and compacting. The estimate assumes that importing/disposing soil or significant grading and drainage would not be required at any of the sites. If additional features at the sites are desired (*e.g.*, base rock, paving), these would need to be added to the total development costs. Large amounts of vegetation removal (*e.g.*, vineyards) would also be extra.

F. Grid Interconnection

PG&E estimated interconnection costs for a variety of possible configurations. Costs can vary significantly depending on the design and capacity of the particular substation and feeder, the amount of MW to be injected, and the location of the interconnection point. The value shown in Table 4-1, line 3, corresponds to a mix of interconnection configurations that PG&E judged most likely to be used in the PV UOG Program.

G. Security and SCADA

Security includes fences and monitoring equipment. Security and plant performance monitoring data are connected to the PG&E SCADA network. The estimated cost, shown in Table 4-1, line 4, was developed by scaling costs for similar, recently completed PG&E projects to the solar field dimensions, expected site locations, and data requirements.

H. PG&E Supervisory Labor, Consulting Support, and Permits

PG&E's cost estimate on line 5 of Table 4-1 is for labor and consulting support to supervise land acquisition and permitting activities, to conduct biological surveys, to conduct environmental site assessments, to locate properties and negotiate land purchases, to prepare site plans and construction bid documents, to prepare solicitation documents and evaluate and award bids, to supervise field construction, to manage the PV UOG Program schedule and budgets, and for fees, permits and implementation of permit terms and conditions.

I. Contingency

PG&E used different contingency factors for the PV UOG Program cost elements depending on the level of variability and uncertainty in the estimates: a 10 percent contingency for the turnkey solar field, 33 percent for land acquisition and permitting, 20 percent for grid interconnection, 15 percent for site preparation, 18 percent for Security/SCADA, and 0 percent for supervisory labor and consulting support. The contingency amount is shown on line 7 of Table 4-1.

J. Pilot Project

PG&E plans to initiate the PV UOG Program by building a PV Pilot Project starting in 2009. The estimated cost of the PV Pilot Project is $11.9 million. The basis for this cost estimate is the same as for the larger PV UOG Program, as described above. The PV system contract pricing is based on indicative vendor quotations. The land cost was estimated to be zero, assuming PG&E land will be used. The grid interconnection cost is based on a specific site under consideration. Other costs are scaled from the baseline 5 MW project size to the nominal 2 MW pilot size. No contingency costs are included in the

PV Pilot Project estimate. If vendor bids are higher than estimated, PG&E will reduce the size of the PV Pilot Project to match the targeted estimated cost.

K. Conclusion

This chapter presents PG&E's estimated capital costs for the PV UOG Program. The capital costs presented in this chapter are reasonable and form the basis of the revenue requirement and ratemaking presented in Chapter 6.

PACIFIC GAS AND ELECTRIC COMPANY

CHAPTER 5

OPERATIONS AND MAINTENANCE COSTS

PACIFIC GAS AND ELECTRIC COMPANY
CHAPTER 5
OPERATIONS AND MAINTENANCE COSTS

TABLE OF CONTENTS

A. Operations and Maintenance Costs: Photovoltaic Utility-Owned Generation Program 5-1

1. Introduction 5-1

2. Summary 5-1

3. Basis of Design and Cost Assumptions 5-2

4. Description of O&M Costs 5-3

a. PG&E Labor and Preventive Maintenance 5-3

b. Safety, Security and Compliance 5-4

c. Infrastructure 5-4

d. Consumables and Materials 5-5

e. Corrective Maintenance 5-5

f. Contracts: Panel Washing 5-5

g. Contracts: Vendor Service Agreement 5-6

5. Contingency on O&M Costs 5-6

B. PV Pilot Project O&M Costs 5-6

C. Conclusion 5-7

PACIFIC GAS AND ELECTRIC COMPANY
CHAPTER 5
OPERATIONS AND MAINTENANCE COSTS

A. Operations and Maintenance Costs: Photovoltaic Utility-Owned Generation Program

1. Introduction

This chapter describes the operating and design characteristics of the Photovoltaic Utility-Owned Generation Program (PV UOG Program) facilities, which determine the subsequent Operations and Maintenance (O&M) expenditure requirements to support their ongoing safe, compliant, reliable and cost-effective operation.[1] This chapter presents the O&M expenses for the first five years of commercial operation that are used in the development of the initial revenue requirement presented in Chapter 6.

2. Summary

After the PV facilities achieve commercial operation, O&M expenditures will be required to ensure safe, compliant, reliable and cost-effective operation. Pacific Gas and Electric Company's (PG&E or the Company) estimate of the O&M costs, including contingency, for the first five years of operation is summarized in Table 5-1 below.

[1] In this chapter, all references to the electrical output capability are presented on an alternating current (AC) basis unless denoted otherwise. Costs are represented in year 2009 dollars.

TABLE 5-1
PACIFIC GAS AND ELECTRIC COMPANY
O&M COSTS INCLUDING CONTINGENCY
(2009 THOUSAND DOLLARS)

Line No.	Year of Operation	First	Second	Third	Fourth	Fifth
1	PG&E Labor and Preventive Maintenance	619	889	1,159	1,428	1,833
2	Corrective Maintenance	31	94	157	220	315
3	Safety/Security/Compliance	29	87	146	204	291
4	Infrastructure	153	460	767	1,074	1,534
5	Consumables and Materials	6	17	28	39	55
6	Contracts	250	750	1,250	1,750	2,500
7	Contingency	218	459	701	943	1,306
8	Total O&M Including Contingency	1,306	2,756	4,207	5,657	7,833

3. Basis of Design and Cost Assumptions

This section describes the technical aspects of typical solar facilities which were used as the basis for the O&M costs required to operate and support the facilities. The UOG portion of the PV Program will consist of up to 250 megawatts (MW) dispersed over a number of locations determined by solar performance, interconnection cost, and land availability along with other factors. Basic design components for the solar facilities include a standard configuration consisting of “strings” of PV panels with each string connected to a 0.5 MW or 1 MW inverter. Multiple strings and inverters located on a project site determine the size of the installation up to 20 MW. The O&M estimates are based upon the simplifying assumptions that the average site will produce 5 MW and the 250 MW PV UOG Program total will be installed according to the quantities shown in Table 5-2, below, and outlined in Chapter 2.

TABLE 5-2
PACIFIC GAS AND ELECTRIC COMPANY
PROGRAM INSTALLATION QUANTITIES

Line No.	Year of Operation	First	Second	Third	Fourth	Fifth
1	MW of installed PV Systems Per Year, AC	25	50	50	50	75
2	Cumulative MW of Installed PV Systems Per Year, AC	25	75	125	175	250

The O&M estimates are based upon a fixed-panel design. Movable panels that track the motion of the sun have the potential to provide greater

energy production than the fixed panel design, at increased capital and ongoing maintenance expenditures. Should the Company ultimately choose to implement a tracking panel design, additional O&M expenditures will be required.

Because the volume of PV facilities installed may vary from year to year, the annual O&M costs can be expressed on a normalized basis in terms of dollars per kilowatt-year ($/kW-yr). Table 5-3, below, presents the O&M costs in this fashion. As some costs vary directly with the volume of PV facilities installed, the actual O&M expenditures required for a given year will vary based upon the actual number of MW installed.

TABLE 5-3
PACIFIC GAS AND ELECTRIC COMPANY
O&M COSTS INCLUDING CONTINGENCY
($2009/KW-YR)

Line No.	Year of Operation	First	Second	Third	Fourth	Fifth
1	Annual O&M ($/kW-yr) AC	52.24	36.75	33.66	32.33	31.33

4. Description of O&M Costs

As the solar facilities are brought online, PG&E will incur ongoing O&M costs for their operation. O&M consists of labor, materials, and contracts to support the routine O&M of the facilities.

a. PG&E Labor and Preventive Maintenance

PG&E's staffing plan assumes that the PV facilities will be monitored remotely from an existing PG&E facility with existing operating personnel. Existing PG&E personnel will monitor the multiple solar sites from a high level, with the ability to "drill down" to finer levels of detail for troubleshooting and failure determination. Operating personnel will monitor high-level information from each solar facility, including the following:

1. PV site power output;
2. PV site power output relative to expected output, or deviation from expected output;
3. PV site voltage output;

4. Main breaker status; and
5. High level trouble alarms.

PG&E personnel will also monitor PV site security.

Additionally, PG&E personnel will perform regular anticipated preventive maintenance tasks, including annual inspections of all solar facility inverters, as well as instrument calibration, to ensure the solar facilities operate in a safe, compliant, and reliable fashion. Other preventive maintenance activities include minor maintenance such as cleaning and replacement of inverter filters, infrared monitoring of key electrical connections, and breaker maintenance.

Based on the standard site sizing assumption of 5 MW, at full build out of the PV UOG Program, eight additional personnel will be required to perform the monitoring and preventive maintenance for the PV facilities. One contract manager will oversee the washing, infrastructure, and miscellaneous contracts. One data analyst will monitor system performance, and coordinate corrective and preventive maintenance activities. Five field technicians will perform preventive maintenance activities. One security person will oversee the additional security support for the PV facilities. The contract manager and data analyst will be added in the first year resulting in a higher $/kW-yr rate for the first two years of operation. Additional personnel will be added as build out takes place in the following years. Labor costs are based on PG&E's fully loaded costs and include benefits, payroll taxes, overtime, and supervision.

b. Safety, Security and Compliance

Safety supplies, equipment, and training are included in the forecast to ensure a safe and compliant workplace. Additionally, PG&E must maintain security systems associated with the PV facilities to assure employee and public safety. Finally, PG&E must ensure it is in compliance with any permit requirements associated with these PV facilities.

c. Infrastructure

The PV facilities require funding for certain infrastructure maintenance activities typical for day-to-day operation of a solar facility.

Examples include pest control, weed abatement, dust suppression, perimeter fence and gate maintenance, and communication and data acquisition software and hardware upgrades. These tasks will be performed by contract personnel as necessary. Additionally, miscellaneous equipment rentals and vehicles will be needed to perform infrequent tasks.

d. Consumables and Materials

The PV facilities also require funding for minor consumables and materials that are typical for day-to-day operation of a solar facility and include inverter air filters, connectors, and replacement of non-warranty covered components.

e. Corrective Maintenance

Actual PV facility performance will be compared to expected performance and analyzed over time. PG&E personnel will monitor performance and respond to changes in performance or other alarms as necessary. If output drops below the expected value, and monitoring personnel cannot determine the cause, field personnel will be dispatched to troubleshoot the problem and perform any repairs that are not covered under warranty or a vendor service agreement. Corrective maintenance may include activities such as inverter repair and replacement of broken panels. PG&E expects to secure multi-year manufacturer's warranties for the inverters and panels and other components. Even with these warranties, a certain degree of PG&E support is required to diagnose equipment problems and facilitate repair of warranty covered equipment.

f. Contracts: Panel Washing

At full build out of the PV UOG Program, roughly 2,500 acres of land occupied by solar panels will be monitored for performance and washed as needed. PG&E will establish a panel-washing contract to facilitate this periodic maintenance function. Panel washing will be performed seasonally on a scheduled basis. More frequent washing may be required depending on the benefits of cleaning compared to the cost. PG&E personnel will track performance output and trends to calculate degradation rate and predict when panel washing should be scheduled

to restore performance. PG&E personnel will oversee panel-washing activities performed by contract personnel to ensure performance requirements are met. Scheduled washing will be planned for two times per year; more frequent washing may be required depending on the benefits of cleaning compared to the cost.

g. Contracts: Vendor Service Agreement

Vendor service agreements are used in the industry as a way to provide high reliability and efficiency of a solar facility. They provide reliability and efficiency benefits while also providing predictable cost streams. Vendor service agreements may be utilized to perform repair or replacement of equipment that is not covered under warranty.

5. Contingency on O&M Costs

PG&E's estimate of ongoing O&M expenditures is based upon estimates from solar equipment suppliers, consultants, and PG&E's best professional judgment. However, since PG&E does not have any significant ownership experience with solar PV facilities, there is some uncertainty in these estimates. Primary areas of uncertainty are driven by site specifics at each project location. A site prone to panel fouling due to dust may require more frequent cleaning than planned in order to maintain performance. If greater than expected vegetation growth results in panel shading, more aggressive weed abatement will be required. If the program results in many sites separated by large distances, costs may increase due to greater inefficiencies when compared to fewer sites that are located closer to each other. Because the commercial operation date will vary over a period of five years, O&M costs estimated today may be substantially different from the forecast due solely to inflation varying from the assumed rate. Given the uncertainties identified in the ongoing operation of the solar facilities, a 20 percent contingency has been applied to the O&M expenditures.

B. PV Pilot Project O&M Costs

In 2009, the Company will implement a PV Pilot Project that will become operable in early 2010. Table 5-4 below, provides the O&M costs associated with the PV Pilot Project based upon the same estimating methodology used for the PV UOG Program.

TABLE 5-4
PACIFIC GAS AND ELECTRIC COMPANY
PV PILOT O&M COSTS INCLUDING CONTINGENCY
(2009 THOUSAND DOLLARS)

Line No.	Year of Operation	First	Second	Third	Fourth	Fifth
1	Total O&M Including Contingency	369	369	369	369	369

C. Conclusion

This chapter provides a reasonable estimate of the costs of operating and maintaining the utility-owned solar facilities to be used in the development of the revenue requirement presented in Chapter 6.

PACIFIC GAS AND ELECTRIC COMPANY

CHAPTER 6

REVENUE REQUIREMENT AND RATEMAKING FOR PG&E'S PHOTOVOLTAIC PROGRAM

PACIFIC GAS AND ELECTRIC COMPANY
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TABLE OF CONTENTS

A. Introduction 6-1

B. Ratemaking Proposal for PV Programs 6-1

1. Ratemaking Proposal for 250 MW PV UOG Program 6-2

a. Recovery of Initial Capital Costs 6-2

b. Initial Revenue Requirement 6-3

c. Adjustments to Initial Revenue Requirement 6-5

2. Ratemaking Proposal for PV Pilot Project 6-5

3. Ratemaking Proposal for Land Deposits 6-6

4. PV PPA Program Cost Recovery 6-6

5. Non-Bypassable Charge 6-7

C. Development of PV Program Revenue Requirements 6-7

1. 250 MW PV UOG Program Revenue Requirement 6-7

2. Development of Average Revenue Requirement per MW 6-8

a. Operation and Maintenance 6-9

b. Uncollectibles and Franchise Expense 6-10

c. Property Taxes 6-10

d. State and Federal Income Tax 6-10

e. Depreciation Expense 6-12

f. Return on Rate Base 6-12

g. Megawatts Installed 6-12

h. Average $/MW 6-12

i. PV UOG Program Rate Base 6-12

(1) Plant 6-13

(2) Accumulated Deferred Taxes 6-13

PACIFIC GAS AND ELECTRIC COMPANY
CHAPTER 6
REVENUE REQUIREMENT AND RATEMAKING FOR PG&E'S PHOTOVOLTAIC PROGRAM

TABLE OF CONTENTS

(CONTINUED)

(3) Accumulated Deferred ITC 6-13

(4) Accumulated Depreciation 6-13

(5) Capital Expenditures 6-14

3. Revenue Requirement for PV Pilot Project 6-14

4. Revenue Requirement for Land Deposits 6-16

D. Levelized Cost of Energy for PV UOG Program 6-17

E. Conclusion 6-17

PACIFIC GAS AND ELECTRIC COMPANY
CHAPTER 6
REVENUE REQUIREMENT AND RATEMAKING FOR PG&E'S PHOTOVOLTAIC PROGRAM

A. Introduction

The purpose of this chapter is to present Pacific Gas and Electric Company's (PG&E or the Company) proposal for recovering the cost of PG&E's proposed Photovoltaic Program (PV Program). This chapter addresses PG&E's cost recovery proposal for the elements of the PV Program. Adoption of PG&E's ratemaking proposal for the PV Utility-Owned Generation Program (PV UOG Program) will assure timely recovery of the reasonable cost of completing, owning and operating the facilities as of the date of commercial operation, while providing PG&E a strong incentive to develop and build the facilities at or below the reasonable and prudent cost determined by the California Public Utilities Commission (CPUC or Commission). In addition, this chapter describes the proposed ratemaking recovery for PG&E's PV Pilot Project, land deposits, and PV Power Purchase Agreement Program (PV PPA Program).

B. Ratemaking Proposal for PV Programs

As discussed in Chapter 1, the components of the PV Program include:

1. PV UOG Program;
2. PV Pilot Project;
3. Land deposits; and
4. PV PPA Program.

PG&E requests that the Commission adopt its ratemaking proposal presented in this chapter for each element of the PV Program. The estimated annual revenue requirement associated with the utility-owned components of the PV Program is shown in Table 6-1.

TABLE 6-1
PACIFIC GAS AND ELECTRIC COMPANY
SUMMARY OF UTILITY-OWNED PV PROGRAM REVENUE REQUIREMENTS
(THOUSANDS OF NOMINAL DOLLARS)

Line No.		2010	2011	2012	2013	2014
1	PV UOG Program	13,559	47,744	87,685	123,755	168,629
2	PV Pilot	2,261	1,964	1,862	1,766	1,694
3	Land Deposits	675	573	433	291	110
4	Total Revenue Requirement	16,495	50,280	89,980	125,813	170,432

The utility-owned and PPA components of the PV Program are described in more detail below.

1. Ratemaking Proposal for 250 MW PV UOG Program

a. Recovery of Initial Capital Costs

PG&E estimates the capital cost to complete the PV UOG Program to be $1.454 billion. This corresponds to the average capital cost target of $4,275/kilowatt (kW) direct current (DC) for the 5-year, 250 megawatts (MW) PV UOG Program described in Chapters 2 and 4. PG&E requests the Commission find that the annual price targets in Table 6-2 are reasonable and prudent cost targets for the PV UOG Program.

TABLE 6-2
PACIFIC GAS AND ELECTRIC COMPANY
$/kW CAPITAL TARGET BY YEAR
(2009 DOLLARS DC)(a)

Line No.		2010	2011	2012	2013	2014	Average
1	$/kW $2009 DC	4,448	4,081	3,843	3,667	3,559	3,831
2	Contingency	499	470	445	427	419	444
3	$/kW Target $2009 DC	4,947	4,551	4,288	4,094	3,978	4,275

(a) PG&E will adjust actual program dollars based on Consumer Price Index (CPI) and DC to alternating current (AC) conversion factor of 0.82.

PG&E requests that the initial revenue recovery of the PV UOG Program be based on the estimated cost targets submitted by PG&E in this Application. If the actual total capital costs are at or below the

average target at the end of the 5-year PV UOG Program period, PG&E will be allowed to recover the actual capital cost of the PV UOG Program without any further reasonableness review. To the extent the total capital costs are less than the average target, customers will be refunded the difference. In the event that the average installed cost of the PV UOG Program exceeds the average target, PG&E would be allowed to recover the actual capital costs up to the average target. In addition, PG&E would be entitled to file an application with the Commission for recovery of amounts in excess of the average target to the extent the amounts in excess are subsequently found to have been reasonably incurred.

If circumstances cause the PV UOG Program to be terminated early, the capital target would be the weighted average of the annual targets for the years up to termination.

PG&E is requesting the rate of return on rate base equal to the currently authorized rate of return of 8.79 percent adopted in Decision 07-12-049 for 2008, plus 1 percent for renewable assets as allowed by Decision 06-05-039.

b. Initial Revenue Requirement

To allow for recovery of the costs of owning and operating the UOG PV facilities, PG&E requests that the Commission adopt an estimated average revenue requirement per MW of installed capacity for each year of the PV UOG Program, as shown in Table 6-3.

TABLE 6-3
PACIFIC GAS AND ELECTRIC COMPANY
250 MW PV UOG PROGRAM
AVERAGE $/MW BY PROGRAM YEAR
(THOUSANDS OF NOMINAL DOLLARS)

Line No.	Program Year(a)	2010	2011	2012	2013	2014
1	2010 Projects	1,085	923	864	808	764
2	2011 Projects		1,008	857	802	749
3	2012 Projects			975	829	776
4	2013 Projects				953	811
5	2014 Projects					942

(a) For purposes of this table, PG&E assumes the PV UOG Program starts on January 1, 2010. PG&E proposes to start the PV UOG Program on the date the first operational facility comes online, and that the first year will be 12 months from that date. If there is a considerable delay in the start of the PV UOG Program, these numbers may need to be updated for additional escalation.

The average annual revenue requirement in Table 6-3 is based on the capital costs and the operation and maintenance (O&M) costs of the PV UOG Program. The development of the average annual revenue requirement is described in more detail in Section C below. PG&E proposes to charge customers only for actual MW of capacity installed. As of the date of each facility, PG&E will begin to accrue revenues equal to the $/MW shown in Table 6-3 times the MW capacity of the facility. For example, if in July 2010, a 1 MW facility becomes operational, PG&E will begin to accrue revenue requirements of $90,417/month ($1,085,000/12 months) in the Utility Generation Balancing Account (UGBA) for the next 12 months. In July 2011, the accrual for that facility will be reduced to $76,917/month ($923,000/ 12 months). Recovery of the 2010 revenue requirement will begin on January 1 of the following year. This initial revenue requirement will remain in effect until superseded by the revenues that will be established in a General Rate Case (GRC) following commercial operation of the facility. PG&E anticipates including these costs in the GRC filed subsequent to the 2011 GRC (currently expected in 2014).

Revenues for all of the components of PG&E's PV Program will be collected in generation rates. New rates to recover the PV UOG

Program costs will be designed based upon the then-current adopted methods for setting electric rates for generation revenue requirement changes.

c. Adjustments to Initial Revenue Requirement

Before the end of each year of the PV UOG Program, PG&E will file an advice letter to update the following year's average annual revenue requirement to reflect the then-current cost of capital, franchise and uncollectibles factors, and property tax factors, if there have been changes. At the end of the PV UOG Program, PG&E will file an advice filing to revise the previous years' revenue requirements to reflect the actual capital cost of the program if the average installed cost is below the capital target. As mentioned above, if the actual capital costs exceed the target, PG&E can recover the costs in excess of the target only after the costs are found reasonable in a separate application.

PG&E will establish a memorandum account to record the difference between the revenue requirement booked to UGBA and the revenue requirement based on the actual capital cost of the PV UOG Program. If the actual capital costs are lower than the target, the amount in the memorandum account will be returned to customers at the end of the 5-year program. If the actual capital costs exceed the target, the amount in the memorandum account will only be collected upon a finding that the costs above the target were reasonably incurred in a separate application.

2. Ratemaking Proposal for PV Pilot Project

To allow for recovery of the costs of owning and operating the PV Pilot Project, PG&E requests that the Commission adopt the estimated 2010 revenue requirement on line 2 of Table 6-1. The development of the PV Pilot revenue requirement is described in more detail below in Section C. PG&E proposes that the revenue requirement be recorded in UGBA as of the date of commercial operation of the PV Pilot Project. After commercial operation, PG&E will file an advice letter to update the revenue requirement for the PV Pilot Project to reflect the actual capital costs of the PV Pilot Project. This initial revenue requirement will remain in effect until superseded by the revenues that will be established in a GRC following

commercial operation of the facility. PG&E anticipates including these costs in the GRC filed subsequent to the 2011 GRC (currently expected in 2014).

PG&E will establish a memorandum account to record the difference between the revenue requirement booked to UGBA for the PV Pilot Project and the revenue requirement based on the actual capital cost of the PV Pilot Project. After commercial operation of the PV Pilot Project, PG&E will file an advice letter to transfer the balance in the memorandum account to UGBA.

3. Ratemaking Proposal for Land Deposits

To allow for recovery of the carrying costs of land deposits prior to operation of the PV facilities, PG&E proposes to include the land deposits in Plant Held for Future Use (PHFU).[1] As PG&E places the PV facilities in service the deposits will be transferred to plant in service as part of the capital cost of the facility. Line 3 of Table 6-1 shows the revenue requirement associated with the carrying costs of the deposits between the time they are purchased and the time the costs are transferred to plant in service. The development of the land deposits revenue requirement is described in more detail below in Section C. When PG&E pays for the land deposits it will accrue the revenue requirement in UGBA. PG&E will pro-rate the UGBA accrual to reflect only the actual land deposit costs.

4. PV PPA Program Cost Recovery

PG&E proposes to recover the cost of the PV PPAs through its Energy Resource Recovery Account (ERRA). The ERRA was established to record the authorized ERRA revenue requirement and ERRA actual power costs to determine the recovery of PG&E's procurement plan power costs, excluding costs associated with the California Department of Water Resources (CDWR) power contracts. PG&E's power costs include, as defined in Decision 02-10-062 and modified by Decision 02-12-074, utility retained generation (URG) fuels, Qualifying Facility (QF) contracts, inter-utility contracts, California Independent System Operator (CAISO) charges, irrigation district contracts and other PPAs, bilateral contracts, forward

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[1] For property acquired in advance for future utility use, the Commission may allow the utility to earn a cash return on the cost of the property, without any depreciation expense, until the time that the property is placed in service. This type of property is referred to as Plant Held for Future Use.

hedges, pre-payments and collateral requirements associated with procurement, and ancillary services, along with other related power procurement costs. Therefore, ERRA is the appropriate mechanism for recovery of the costs associated with the PV PPAs.

5. Non-Bypassable Charge

Under Commission decisions, PG&E is entitled to recover stranded costs associated with the PV Program through a non-bypassable charge. For the PV PPA Program, PG&E is entitled to recover any stranded costs associated with the PPAs over the entire term of the agreements.[2] In addition, stranded costs associated with the PV UOG Program can be recovered for each facility installed for a 10-year period following commercial operation of the facility.[3] PG&E will implement the non-bypassable charge cost recovery for the PV Program consistent with the Commission's direction in Decision 08-09-012.

C. Development of PV Program Revenue Requirements

1. 250 MW PV UOG Program Revenue Requirement

Table 6-4 shows the average MW installed by Program Year for the PV UOG Program.

TABLE 6-4
PACIFIC GAS AND ELECTRIC COMPANY
250 MW PV UOG PROGRAM
AVERAGE MW INSTALLED BY PROGRAM YEAR

Line No.	Program Year	2010	2011	2012	2013	2014
1	2010 Projects	12.5	25	25	25	25
2	2011 Projects		25	50	50	50
3	2012 Projects			25	50	50
4	2013 Projects				25	50
5	2014 Projects					37.5

The estimated annual revenue requirement for 2010 through 2014 for each year of the PV UOG Program commercial operation is shown in Table 6-5.

[2] D.08-09-012, pp. 55-57.

[3] D.04-12-048, Conclusion of Law 16; D.08-09-012, pp. 52-55.

TABLE 6-5
PACIFIC GAS AND ELECTRIC COMPANY
250 MW PV UOG PROGRAM
REVENUE REQUIREMENT BY PROGRAM YEAR
(THOUSANDS OF NOMINAL DOLLARS)

Line No.	Year	2010	2011	2012	2013	2014
1	2010 Projects	13,559	23,066	21,600	20,200	19,092
2	2011 Projects	–	25,205	42,830	40,077	37,446
3	2012 Projects	–	–	24,369	41,445	38,800
4	2013 Projects	–	–	–	23,829	40,557
5	2014 Projects	–	–	–	–	35,308
6	Total	13,559	48,270	88,799	125,551	171,202

The revenue requirements in Table 6-5 were developed by multiplying the average $/MW in Table 6-2 by the average MW installed for each PV UOG Program year in Table 6-4.

As mentioned above, PG&E requests that the Commission adopt the average revenue requirements/MW in Table 6-2. As PV facilities are installed, PG&E will accrue revenues in UGBA equal to the installed capacity multiplied by the average $/MW in Table 6-2. This allows for flexible deployment of the PV UOG Program without potential large over- or under-collection of revenues.

2. Development of Average Revenue Requirement per MW

Table 6-6 shows development of the average revenue requirement for 2010 to 2014 for the 2010 projects of the PV UOG Program.

TABLE 6-6
PACIFIC GAS AND ELECTRIC COMPANY
250 MW PV UOG PROGRAM
REVENUE REQUIREMENT FOR 2010 PROJECTS
(THOUSANDS OF NOMINAL DOLLARS)

Line No.	Description	2010	2011	2012	2013	2014
1	Operating Revenue	27,117	22,645	21,076	19,617	18,458
2	Operating Expenses					
3	Fixed O&M	1,359	982	923	910	903
4	Uncollectibles	70	58	54	51	48
5	Franchise Requirements	205	171	159	148	139
6	Subtotal Expenses	1,634	1,212	1,137	1,108	1,090
7	Taxes					
8	Property	1,862	1,788	1,714	1,640	1,566
9	State Corporation Franchise	1,151	236	243	210	198
10	Federal Income	5,395	3,740	3,701	3,317	3,032
11	Subtotal Taxes	8,408	5,764	5,659	5,168	4,797
12	Depreciation	6,259	6,259	6,259	6,259	6,259
13	Total Operating Expenses	16,301	13,235	13,055	12,535	12,145
14	Net for Return	10,816	9,410	8,021	7,082	6,312
15	Weighted Average Ratebase	110,484	96,115	81,926	72,338	64,475
16	Rate of Return	9.79%	9.79%	9.79%	9.79%	9.79%
17	MW Installed	25	25	25	25	25
18	Average $/MW	1,085	906	843	785	738

The development of the average $/MW for PV UOG Program years 2011 through 2014 are shown in the supporting workpapers to this chapter.

a. Operation and Maintenance

The O&M expense shown on line 3 of Table 6-6 is the estimated cost of operating and maintaining the PV UOG Program. The development of these costs is presented in Table 6-7.

TABLE 6-7
PACIFIC GAS AND ELECTRIC COMPANY
DEVELOPMENT OF PV UOG PROGRAM O&M EXPENSE
2010 PROJECTS
(THOUSANDS OF DOLLARS)

Line No.		2010	2011	2012	2013	2014
1	O&M Expenses – $2009 AC	1,306	919	841	808	783
2	Escalation	53	63	82	101	119
3	Total O&M Expense	1,359	982	923	910	903

Line 1 of Table 6-7 is the constant dollar O&M expense forecast for the 2010 Projects of the PV UOG Program included in the O&M forecast from Chapter 5. Line 2 is the escalation from constant 2009 dollars to nominal dollars.[4] Line 3 is the total nominal O&M for the 2010 Projects of the 250 MW PV UOG Program.

b. Uncollectibles and Franchise Expense

Uncollectible accounts expenses and franchise fees are shown on lines 4 and 5, respectively, of Table 6-6. These amounts are a function of revenue requirements and are developed using historical factors. The initial revenue requirement will be adjusted to reflect the then-current franchise and uncollectibles factors by advice letter as discussed above.

c. Property Taxes

Line 8 of Table 6-6 is the estimated property tax for the PV UOG Program. Property taxes are calculated based on the value of plant as of the property tax lien date multiplied by a property tax factor based in the historical relationship of property tax assessments to recorded plant balances. The initial revenue requirement will be adjusted to reflect the then-current property tax factor by advice letter as discussed above.

d. State and Federal Income Tax

Estimated California Corporation Franchise Tax (CCFT) and federal income tax (FIT) are shown on lines 9 and 10, respectively, of Table 6-6.

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[4] The O&M labor costs have been escalated using terms from PG&E's most recent labor contracts. The non-labor O&M costs have been escalated using CPI.

CCFT and FIT expenses are estimated based on net operating income before income taxes. Current tax law has been utilized to compute income taxes for the facility.

FIT expense, including deferred income tax, is calculated by multiplying the currently effective corporate FIT rate of 35 percent by applicable federal taxable income. Similarly, state income tax expense is calculated by multiplying the statutory rate of 8.84 percent of state taxable income. Following established Commission policy, FITs are computed on a normalized basis. Deferred FITs are calculated as the difference between book depreciation and federal tax depreciation times the federal tax rate. The Accumulated Deferred FIT is included as a credit to rate base. Federal tax depreciation is based on the 5-year Modified Accelerated Cost Recovery System (MACRS) schedule.

As a result of the Jobs Act of 2004, PG&E is eligible to receive an additional FIT deduction (as of the date of this filing, California has not conformed to this act). The Jobs Act of 2004 includes a provision that allows a tax deduction for goods manufactured and produced in the United States. The deduction is computed as a percentage of the net taxable income of a taxpayer derived from the manufacture or production of such goods.**[5]** The rate is phased in beginning at 3 percent for 2005, and increasing to 9 percent beginning in 2010. Production of electricity qualifies for the deduction; the transmission and distribution of electricity does not. The initial revenue requirement calculation reflects the appropriate tax savings associated with the Jobs Act of 2004.

State income taxes are calculated on a flow-through basis. State tax depreciation is based on a Double Declining Balance (DDB) method over 20 years.

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[5] The Internal Revenue Code (IRC) section uses the term qualified production activities income and defines that as gross receipts, reduced by the sum of: (1) cost of goods sold that are allocable to the receipts; (2) other deductions, expenses, or losses that are directly allocable to such receipts; and (3) a proper share of other deductions, expenses, and losses that are not directly allocable to such receipts or another class of income. Internal Revenue Code §199(c)(1).

e. Depreciation Expense

Depreciation expense (line 12 of Table 6-6) is determined by dividing the plant balance by the 25 year expected life of the facility. This approach assumes zero net salvage for the PV facilities. In the GRC in which the PV Program is included, we will present a detailed depreciation and decommissioning study for the PV facilities.

f. Return on Rate Base

Return on rate base (line 14 of Table 6-6) is calculated by multiplying the estimated rate base by 9.79 percent. This rate of return equals the currently authorized rate of return of 8.79 percent adopted in Decision 07-12 049 for 2008, plus 1 percent for renewable assets as allowed by Decision 06 05 039. The return on rate base will be adjusted to reflect the currently authorized rate of return in effect at the time of the advice filing prior to commercial operation. The initial revenue requirement will be adjusted to reflect the then-current authorized rate of return by advice letter as discussed above.

g. Megawatts Installed

Line 17 of Table 6-6 shows the megawatts expected to be installed in year 1 of the 250 MW PV Program.

h. Average $/MW

In line 18 of Table 6-6, the average $/MW, is derived by dividing line 1 by line 13.

i. PV UOG Program Rate Base

Table 6-8 shows estimated weighted average rate base for the PV UOG Program for the first year of commercial operation.

TABLE 6-8
PACIFIC GAS AND ELECTRIC COMPANY
RATEBASE 2010 PROJECTS
(THOUSANDS OF NOMINAL DOLLARS)

Line No.		2010	2011	2012	2013	2014
1	Plant	160,685	160,685	160,685	160,685	160,685
2	Less Adjustments					
3	Deferred Taxes	3,594	13,478	23,183	28,287	31,665
4	Deferred ITC	43,477	41,702	39,928	38,153	36,379
5	Subtotal Adjustments	47,071	55,181	63,111	66,440	68,044
6	Accumulated Depreciation	3,130	9,389	15,648	21,907	28,166
7	Weighted Average Ratebase	110,484	96,115	81,926	72,338	64,475

A discussion of the substantive components of rate base shown in Table 6-8 follows:

(1) Plant

Line 1 of Table 6-8 shows the Plant in Service balance for the first year of the PV UOG Program. This is equal to the 2010 total capital expenditures from line 11 of Table 6-9.

(2) Accumulated Deferred Taxes

Accumulated Deferred Federal Taxes are shown as a deduction from rate base in line 3 of Table 6-8. This is calculated according to the income tax normalization provision of the Economic Recovery Tax Act, and is consistent with the calculation of FIT expense described above.

(3) Accumulated Deferred ITC

Accumulated Deferred Investment Tax Credit (ITC) is shown on line 4 of Table 6-8. The ITC for the facilities is handled consistent with the ratemaking treatment of ITC approved by the Commission in Decision 93848, and IRC Sections 50(d)(2) and 46(f)(1).

(4) Accumulated Depreciation

The estimated accumulated depreciation is deducted from rate base as shown on line 6 in Table 6-8.

(5) Capital Expenditures

Chapter 4 presents capital dollars for the PV UOG Program on a $/kW DC basis in constant 2009 dollars. In order to determine the revenue requirement, it is necessary to convert the $/kW numbers into total capital expenditures on a nominal AC basis with contingency and overheads. Table 6-9 shows this conversion.

TABLE 6-9
PACIFIC GAS AND ELECTRIC COMPANY
DEVELOPMENT OF PV PROGRAM CAPITAL EXPENDITURES

Line No.		2010	2011	2012	2013	2014		
1	$/kW 2009$ DC	4,448	4,081	3,843	3,667	3,559		
2	Contingency	499	470	445	427	419		
3	$/kW Target 2009$ DC	4,947	4,551	4,288	4,094	3,979		
4	Escalation	77	159	251	333	411		
5	$/kW Nominal $	5,025	4,710	4,539	4,426	4,389		
6	DC/AC Conversion	1,103	1,034	996	972	963		
7	$/kW Nominal $ AC	6,128	5,744	5,535	5,398	5,353		
8	Overheads	300	270	261	255	249		
9	$/kW Nominal AC	6,427	6,014	5,796	5,653	5,601		
10	Capacity (in MW)	25	50	50	50	75		
11	Total Capital Expenditures(a)	160,685	300,712	289,824	282,665	420,094	=	1,453,979

(a) In Thousands of Dollars

3. Revenue Requirement for PV Pilot Project

Table 6-10 shows the development of the revenue requirement for the PV Pilot Project. Table 6-11 shows the development of the rate base used in Table 6-10. See Section C2 above for an explanation of the components of Tables 6-10 and 6-11.

TABLE 6-10
PACIFIC GAS AND ELECTRIC COMPANY
PV PILOT PROJECT REVENUE REQUIREMENT
(THOUSANDS OF NOMINAL DOLLARS)

Line No.		2010	2011	2012	2013	2014
1	Operating Revenue	2,261	1,964	1,862	1,766	1,694
2	Fixed O&M	383	396	411	425	440
3	Uncollectibles	6	5	5	5	4
4	Franchise Requirements	17	15	14	13	13
5	Subtotal Expenses	406	416	429	443	457
6	Taxes					
7	Property	137	132	126	121	115
8	State Corporation Franchise	80	10	10	8	7
9	Federal Income	384	261	258	228	207
10	Subtotal Taxes	601	402	394	357	329
11	Depreciation	475	475	475	475	475
12	Total Operating Expenses	1,482	1,293	1,298	1,275	1,261
13	Net for Return	779	671	564	492	433
14	Weighted Average Rate Base	7,957	6,850	5,758	5,023	4,424
15	Rate of Return	9.79%	9.79%	9.79%	9.79%	9.79%

TABLE 6-11
PACIFIC GAS AND ELECTRIC COMPANY
PV PILOT PROJECT RATE BASE
(THOUSANDS OF NOMINAL DOLLARS)

Line No.	Description	2010	2011	2012	2013	2014
1	Plant	11,867	11,867	11,867	11,867	11,867
2	Less Adjustments					
3	Deferred Taxes	280	1,051	1,807	2,205	2,468
4	Deferred ITC	3,392	3,254	3,115	2,977	2,838
5	Subtotal Adjustments	3,672	4,304	4,922	5,182	5,307
6	Accumulated Depreciation	237	712	1,187	1,661	2,136
7	Weighted Average Ratebase	7,957	6,850	5,758	5,023	4,424

4. Revenue Requirement for Land Deposits

Table 6-12 shows the development of the revenue requirement for the land deposit costs. As mentioned above, this revenue requirement is intended to recover the carrying costs associated with the time between payment of the land deposit and their inclusion in the cost of the PV facilities.

TABLE 6-12
PACIFIC GAS AND ELECTRIC COMPANY
LAND DEPOSIT REVENUE REQUIREMENT
(THOUSANDS OF NOMINAL DOLLARS)

Line No.		2010	2011	2012	2013	2014
1	Operating Revenue	675	573	433	291	110
	Operating Expense					
2	Uncollectibles	2	1	1	1	0
3	Franchise Requirements	5	4	3	2	1
4	Subtotal Operating expenses	7	6	4	3	1
	Taxes					
5	Property	53	45	34	23	9
6	State Corporation Franchise	43	36	27	18	7
7	Federal Income	154	131	99	66	25
8	Subtotal Taxes	250	212	160	108	41
9	Net For Return	419	355	269	181	68
10	Weighted Average Rate Base	4,762	4,037	3,055	2,054	774

TABLE 6-13
PACIFIC GAS AND ELECTRIC COMPANY
LAND DEPOSIT RATE BASE
(THOUSANDS OF NOMINAL DOLLARS)

Line No.		Payment	2010	2011	2012	2013	2014
1	Land in PV Facilities		4,208	8,583	8,755	8,930	13,663
2	Deposit Allocation to Projects	5,000	477	972	992	1,012	1,548
3	Plant Held for Future Use Balance						
4	Beginning Balance		5,000	4,523	3,551	2,559	1,548
5	Transfer to PV Facilities		(477)	(972)	(992)	(1,012)	(1,548)
6	Ending Balance		4,523	3,551	2,559	1,548	–
7	Average Balance		4,762	4,037	3,055	2,054	774

D. Levelized Cost of Energy for PV UOG Program

The levelized cost of energy for the PV UOG Program is $295/megawatt-hour. The $295/megawatt-hour is determined by dividing the net present value (NPV) of the UOG revenue requirement for the life of the program by the NPV of the expected generation of the PV facilities. See the equation below for the development of the levelized cost of energy.

LEVELIZED COST OF ENERGY

	(a)	(b)	(c)=(a)*1000/(b)
NPV	1,367,734	4,635,828	295

The annual revenue requirement assumptions shown above are the same as those used in the UOG revenue requirement in Section C, except that contingency is excluded from the capital expenditures. The generation estimates assume a 24 percent capacity factor with annual degradation of 0.89 percent.

E. Conclusion

PG&E requests the Commission to:

- Adopt the Capital Cost Targets in Table 6-2 as reasonable and prudent capital costs for the PV UOG Program;
- Adopt the Average $/MW Revenue Requirements in Table 6-3 for the PV UOG Program;
- Allow PG&E to establish a Memorandum Account to record the difference between the revenue requirement booked to UGBA and the revenue requirement based on the actual capital cost of the PV UOG Program;
- Approve PG&E's proposal to true-up the Revenue Requirement of the PV UOG Program to reflect the actual capital costs of the program if the actual costs are below the target;
- File for recovery of revenue requirement for capital costs above the target and be allowed to recover those revenue requirements only if the Commission finds that the costs above the target were reasonably incurred;
- Adopt PG&E's proposed revenue requirement for the PV Pilot Project;

- Allow PG&E to establish a memorandum account to record the difference between the revenue requirement booked to UGBA for the PV Pilot Project and the revenue requirement based on the actual capital cost of the PV Pilot Project;
- Allow PG&E to file an advice letter to transfer the balance in the memorandum account to UGBA after commercial operative of the PV Pilot Project;
- Adopt PG&E's proposal for PHFU treatment for land deposits;
- Approve recovery of PV PPA costs through ERRA;
- Approve a Non-Bypassable Charge for the PV PPAs for the life of the contracts;
- Approve a Non-Bypassable Charge for the PV UOG Program facilities for 10 years following commercial operation; and
- Approve a 1 percent increase in the rate of return on rate base for both the PV UOG Program and the PV Pilot Project.

The Commission should adopt PG&E's ratemaking proposal for the PV Program, as it is just and reasonable and will assure PG&E of timely cost recovery of the reasonable cost of the PV Program. PG&E's ratemaking proposal also provides PG&E a strong incentive to develop and build the utility-owned PV facilities at or below the prudent and reasonable cost determined by the Commission, and avoids the need for an after-the-fact reasonableness review in the event the project costs are below the target amounts. It will also allow for timely recovery of the costs associated with the PV PPA program.

PACIFIC GAS AND ELECTRIC COMPANY

APPENDIX A

STATEMENTS OF QUALIFICATIONS

PACIFIC GAS AND ELECTRIC COMPANY
STATEMENT OF QUALIFICATIONS OF DOUG HERMAN

Q 1 Please state your name and business address.

A 1 My name is Doug Herman, and my business address is Pacific Gas and Electric Company, 245 Market Street, San Francisco, California.

Q 2 Briefly describe your responsibilities at Pacific Gas and Electric Company (PG&E or the Company).

A 2 I am a senior project manager in the Renewable Resource Development Department. I am responsible for developing utility owned renewable energy projects.

Q 3 Please summarize your educational and professional background.

A 3 I received a Bachelor of Science degree in mechanical engineering from the University of Santa Clara and a Master of Science degree in energy and resources from the University of California, Berkeley.

I began my current employment with PG&E in 2006 as a senior regulatory specialist in the Energy Proceedings Department. From 2004 to 2006, I was a power industry consultant. From 1993 to 2004, I was a program manager at the Electric Power Research Institute (EPRI) where I managed various emerging technology research, development and demonstration projects. From 1982 to 1993, I managed emerging technology demonstration projects at PG&E in the Mechanical and Nuclear Engineering Department.

Q 4 What is the purpose of your testimony?

A 4 I am sponsoring the following testimony in PG&E's Photovoltaic Program Application:

- Exhibit (PG&E-1), "Photovoltaic Program Prepared Testimony":
  - Chapter 4, "Capital Costs."

Q 5 Does this conclude your statement of qualifications?

A 5 Yes, it does.

PACIFIC GAS AND ELECTRIC COMPANY
STATEMENT OF QUALIFICATIONS OF GARRETT P. JEUNG

Q 1 Please state your name and business address.

A 1 My name is Garrett P. Jeung, and my business address is Pacific Gas and Electric Company, 245 Market Street, San Francisco, California.

Q 2 Briefly describe your responsibilities at Pacific Gas and Electric Company (PG&E or the Company).

A 2 I am a senior director in the Energy Supply Department of Energy Procurement. My primary responsibility is to negotiate long-term energy contracts.

Q 3 Please summarize your educational and professional background.

A 3 I received a Bachelor of Science degree in mechanical engineering and a Masters degree in Business Administration from the University of California, Berkeley. Previously, I was employed by PG&E Corporation's Energy Services as director of Electric Operations and as Chief Strategy Officer of E-lec Trade.

Q 4 What is the purpose of your testimony?

A 4 I am sponsoring the following testimony in PG&E's Photovoltaic (PV) Program Application:

- Exhibit (PG&E-1), "Photovoltaic Program Prepared Testimony":
  - Chapter 3, "Photovoltaic Power Purchase Agreement Program."

Q 5 Does this conclude your statement of qualifications?

A 5 Yes, it does.

PACIFIC GAS AND ELECTRIC COMPANY
STATEMENT OF QUALIFICATIONS OF MICHAEL L. JONES

Q 1 Please state your name and business address.

A 1 My name is Michael L. Jones, and my business address is Pacific Gas and Electric Company, 245 Market Street, San Francisco, California

Q 2 Briefly describe your responsibilities at Pacific Gas and Electric Company (PG&E or the Company).

A 2 I am the director of Generation Development, responsible for developing new generation project opportunities for Utility-Owned Generation (UOG).

Q 3 Please summarize your educational and professional background.

A 3 I received a Bachelor of Science degree in Mechanical Engineering from Washington State University in 1983 and a Master of Business Administration degree from John F. Kennedy University in 1993. I am a registered Mechanical Engineer in the State of California.

In 1983, I joined PG&E as a power production engineer at one of the Company's fossil power plants. From 1983 to 1995, I progressed in both management and technical areas of fossil power plant management, staffing, engineering, operations, maintenance, design, construction, and project management throughout the company's fossil fleet. I trained and guided plant personnel in technical fields such as instrumentation, controls and tuning, vibration and balancing, efficiency testing and evaluation, boiler and turbine design, troubleshooting, and root cause analysis. I ultimately became the plant engineer for the Pittsburg and Contra Costa Power Plants.

From 1995 to 1998 I worked for PG&E Enterprises, PG&E's unregulated affiliate, in a variety of areas including oversight of our unregulated domestic and international generating investments. Additionally, I supported acquisition efforts of electric distribution companies in Australia and South America and power plant acquisition and development efforts in Australia. Work activities included the bid process, due diligence, and development of acquisition transition plans to cover all aspects of the operation of the business including capital investment, operations and maintenance, staffing, industrial relations, and environmental management.

From 1998 to 1999, I returned to PG&E as director of Generation Asset Divestiture and was assigned the task to sell Pittsburg, Contra Costa and Potrero Power Plants, and the Geysers geothermal generating facility as part of PG&E's asset divestiture requirements.

From 1999 to 2001, I was the director and plant manager of Hunters Point Power Plant, a 423 MW conventional fossil and combustion turbine power plant located in San Francisco, California.

As director of Business Projects from 2001 to 2002, I lead a diverse team consisting of operating, inside and outside legal, regulatory, government, corporate, and financial personnel in the Company's bankruptcy Plan of Reorganization transaction effort for the Generation business.

From 2002 to 2006, I was the director of Hydro Operations and Maintenance (O&M). My duties were to lead the O&M organization consisting of 330 people focused on day-to-day safe, reliable, excellent operation of nearly 3,900 MW of hydroelectric generating facilities, organized as 110 generators located in 68 powerhouses in central and northern California. In 2006 to 2007, I worked on the Company's Business Transformation efforts. In my current assignment as director of New Generation Projects, my duties are to develop conventional fossil and hydro power project opportunities for utility investment as well as support the company's solar generation efforts. In the past, I have sponsored testimony for operations and maintenance for Gateway Generating Station (Contra Costa Unit 8) and Tesla Generating Station.

Q 4 What is the purpose of your testimony?

A 4 I am sponsoring the following testimony in PG&E's Photovoltaic (PV) Program Application:

- Exhibit (PG&E-1), "Photovoltaic Program Prepared Testimony":
  - Chapter 5, "Operations and Maintenance Costs."

Q 5 Does this conclude your statement of qualifications?

A 5 Yes, it does.

PACIFIC GAS AND ELECTRIC COMPANY
STATEMENT OF QUALIFICATIONS OF BRIAN M. McDONALD

Q 1 Please state your name and business address.

A 1 My name is Brian M. McDonald, and my business address is Pacific Gas and Electric Company, 245 Market Street, San Francisco, California.

Q 2 Briefly describe your responsibilities at Pacific Gas and Electric Company (PG&E or the Company).

A 2 I am the director of Renewable Resource Development in the Energy Supply organization.

Q 3 Please summarize your educational and professional background.

A 3 I received a Master of Business Administration degree from St. Mary's College of California, a Bachelor of Science degree in Mechanical Engineering from California State University, Sacramento and an Environmental Management Certification from University of California, Berkeley. I am a registered Professional Engineer in the state of California.

I've been a professional in the power, energy, and chemical sector for over 20 years. My expertise is in project development, including project siting/permitting/licensing, financing, project management, and construction management. Prior to joining PG&E in September 2008, I was Vice President of Development and co-founder of Third Planet Windpower. Prior to that, I held various positions at Calpine Corp., including Director of Project Development, Director of Renewables and New Technologies, and Director of Origination. Prior to that, I worked for Enpower (an Independent Power Producer (IPP) in California) as a Program Manager. Prior to that, I worked for several Fortune 500 multinational engineering, procurement, and production (EPC) companies responsible for strategy and program management execution of both national and international multi-billion dollar infrastructure projects in the power, energy, and chemical sectors. I have been involved with the development of over 15,000 MW of both gas-fired combined cycle and renewable power plants across the United States.

Q 4 What is the purpose of your testimony?

A 4 I am sponsoring the following testimony in PG&E's Photovoltaic (PV) Program Application:

- Exhibit (PG&E-1), “Photovoltaic Program Prepared Testimony”:
  - Chapter 2, “Photovoltaic Utility-Owned Generation Program.”

Q 5 Does this conclude your statement of qualifications?

A 5 Yes, it does.

PACIFIC GAS AND ELECTRIC COMPANY
STATEMENT OF QUALIFICATIONS OF JOSEPH F. O'FLANAGAN

Q 1 Please state your name and business address.

A 1 My name is Joseph F. O'Flanagan, and my business address is Pacific Gas and Electric Company, 77 Beale Street, San Francisco, California.

Q 2 Briefly describe your responsibilities at Pacific Gas and Electric Company (PG&E or the Company).

A 2 I am a director in the Senior Vice President – Generation organization and am responsible for various regulatory matters.

Q 3 Please summarize your educational and professional background.

A 3 I received a Bachelor of Science degree in Marine Engineering from the United States Merchant Marine Academy at Kings Point, New York, in 1975. I also attended the Harvard Graduate School of Business Administration, where I was a candidate for a Masters in Business Administration degree.

Prior to joining PG&E in 1979, I served as an engineering officer on ocean-going merchant vessels. Prior to assuming my present position at PG&E, I held the positions of rate economist in the Rates Department, senior valuation engineer in the Valuation Department, supervisor in the Revenue Requirements Department, manager in the Rates, Market Planning and Research, and Revenue Requirements Departments, and director of the Budget, Tax, and Capital Accounting Departments.

Q 4 What is the purpose of your testimony?

A 4 I am sponsoring the following testimony in PG&E's Photovoltaic (PV) Program Application:

- Exhibit (PG&E-1), "Photovoltaic Program Prepared Testimony":
  - Chapter 6, "Revenue Requirement and Ratemaking for PG&E's Photovoltaic Program."

Q 5 Does this conclude your statement of qualifications?

A 5 Yes, it does.

PACIFIC GAS AND ELECTRIC COMPANY
STATEMENT OF QUALIFICATIONS OF FONG WAN

Q 1 Please state your name and business address.

A 1 My name is Fong Wan, and my business address is Pacific Gas and Electric Company, 245 Market Street, San Francisco, California.

Q 2 Briefly describe your responsibilities at Pacific Gas and Electric Company (PG&E or the Company).

A 2 I am a Senior Vice President, Energy Procurement. In this position I am responsible for gas and electric supply planning and policies, market assessment and quantitative analysis, supply development, procurement, and settlement.

Q 3 Please summarize your educational and professional background.

A 3 I graduated from Columbia University in 1984 with a Bachelor of Science degree in Chemical Engineering and from University of Michigan in 1986 with a Master of Business Administration degree.

From 1986 to 1988, I worked as a business analyst with Exxon U.S.A. I began work with PG&E in 1988 as a financial analyst in the financial planning and analysis area. I was promoted to senior financial analyst in 1989 and to manager in 1991. In this area, I worked on recommendations involving capital structure and dividend policies, as well as various capital, acquisition, and divestiture analyses.

From 1992-1993, I was on a special assignment working on the decontracting of Canadian gas supply contracts. In this capacity, I oversaw financial and economic analyses and participated in contract negotiations with suppliers.

In 1994, I joined the Product and Sales Department in California Gas Transmission. I was promoted to director of the department in 1995, where I was responsible for the sales of interstate and intrastate gas transmission capacity and gas storage-related services. I also participated in the development of Gas Accord.

In 1996, I transferred as director to the Power Market Planning Department and the Energy Trading Department. Here, I participated in market structure activities involving the California Independent System

Operators (CAISO) and Power Exchange (PX), and oversaw electric supply planning and trading activities.

In 1997, I left PG&E and joined PG&E Corporation's Energy Trading subsidiary of the National Energy Group, in Bethesda, Maryland. I was promoted to Vice President of Structured Trading in 1999 and my responsibilities encompassed all complex, structured transactions at Energy Trading.

In 1999, I joined AltaGas Inc., in Calgary, Alberta. At AltaGas, I was Senior Vice President and Chief Operating Officer, overseeing all trading, acquisition, strategy and planning, operations, and engineering activities for this midstream gas company.

In 2000, I rejoined PG&E Corporation as Vice President of Risk Initiative, in San Francisco. I participated in PG&E's Plan of Reorganization and advised on power procurement issues.

In 2004, I rejoined PG&E as Vice President of Power Contracts and Electric Resource Development. I oversaw all existing power contracts, including qualifying facility, renewable generation, and irrigation district contracts. In addition, I was also responsible for acquiring all long-term supply needs via contracts or generation ownership.

In 2006, I assumed the position of Vice President of Energy Procurement.

In 2008, I assumed my current position as Senior Vice President of Energy Procurement.

Q 4 What is the purpose of your testimony?

A 4 I am sponsoring the following testimony in PG&E's Photovoltaic (PV) Program Application:

- Exhibit (PG&E-1), "Photovoltaic Program Prepared Testimony":
  - Chapter 1, "Policy Chapter: Executive Summary and Overview of Application."

Q 5 Does this conclude your statement of qualifications?

A 5 Yes, it does.

Summary of PV Potential Assessment in RETI and the 33% Implementation Analysis

Re-DEC Working Group Meeting

December 9, 2009

Energy and Environmental Economics, Inc.

BLACK & VEATCH

Renewable Energy Transmission Initiative

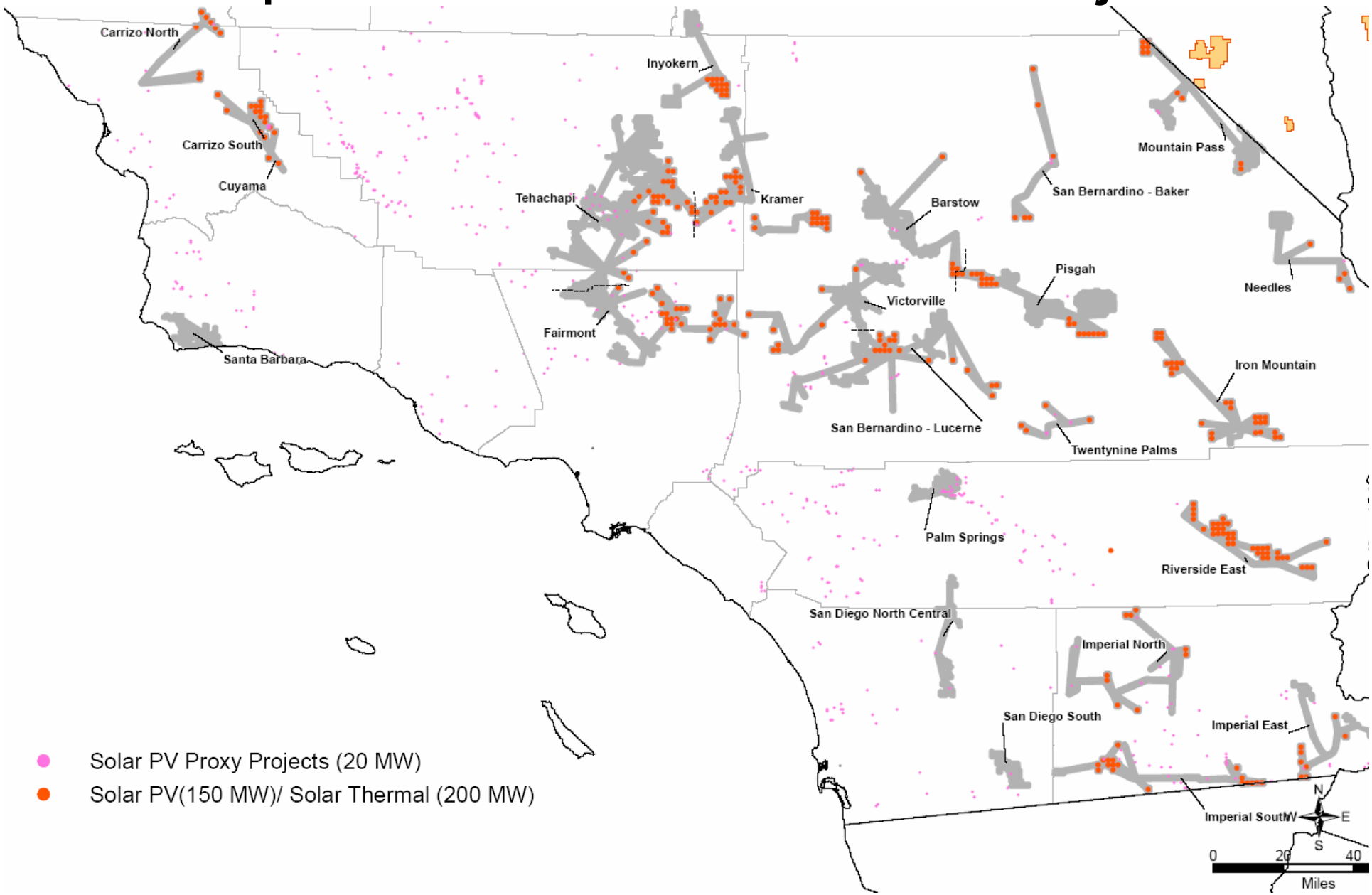
RETI is a statewide planning process to identify transmission projects needed to accommodate California's renewable energy goals.

- California law requires 20% of retail energy sales to come from renewable sources by 2010. The state has also adopted the goal of 33% by 2020.
- Development of renewable generation has slowed in CA. Transmission is a limiting factor.
- RETI is facilitating planning and permitting for competitive renewable energy zones (CREZs)

Solar in RETI

- Large Scale – 150-200 MW, solar thermal or solar PV. Detailed analysis.
- Distributed Wholesale Generation – 20 MW solar PV near substations. Very rough analysis.
- Smaller Systems – Behind the meter applications. Assumed to happen as part of RETI “Net Short” calculation.

Example RETI Phase 1 Solar Projects



- Solar PV Proxy Projects (20 MW)
- Solar PV(150 MW)/ Solar Thermal (200 MW)

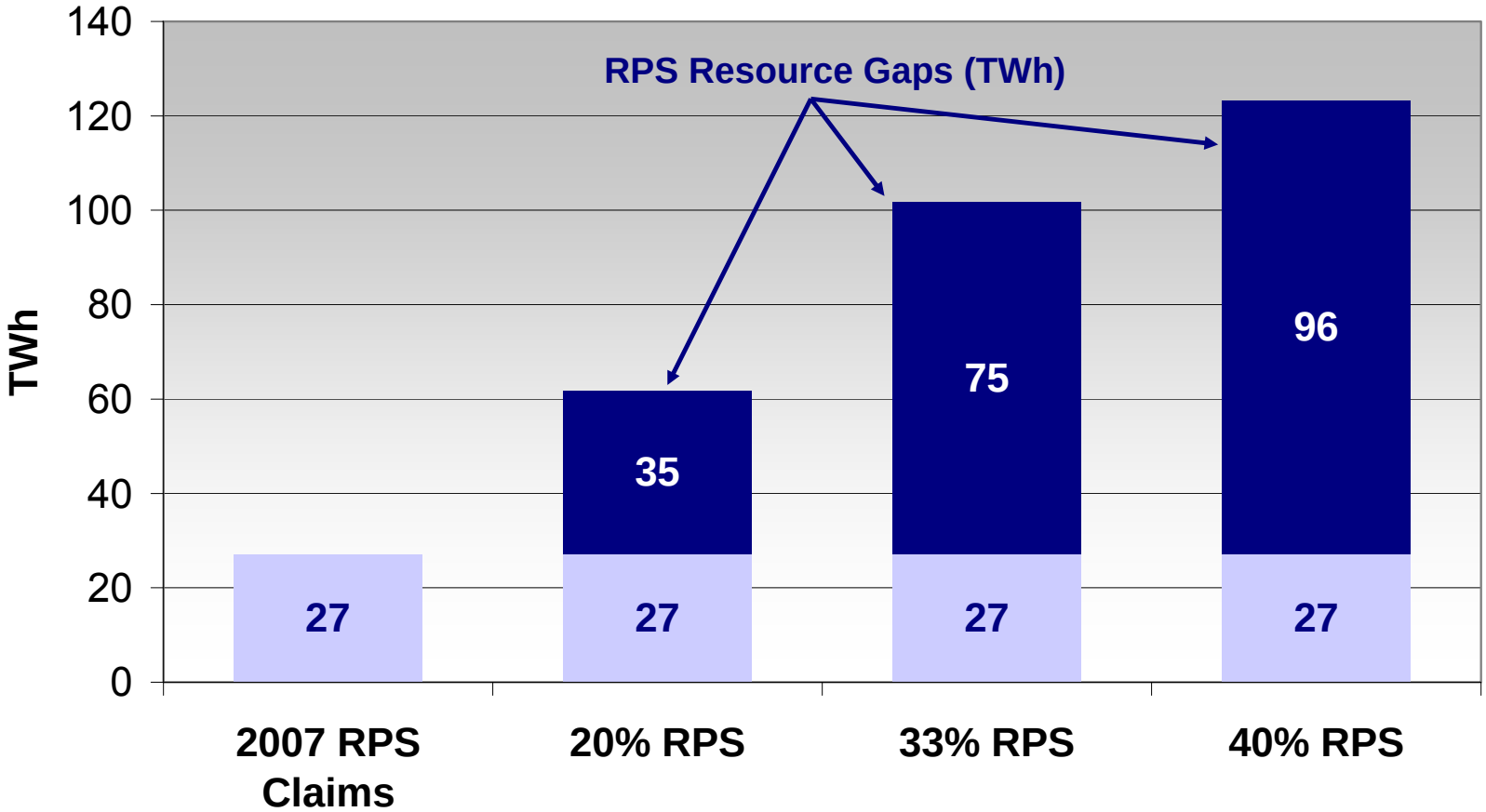
Solar PV Did Not Play a Significant Role In RETI Phase 1 (2008)

- Conventional tracking crystalline technology too expensive to compete
- Thin film technology deemed not fully proven and commercially available
- Thin film sensitivity showed potential for large scale competitiveness – if costs could be reduced ($3700/kW$_{ac}$)

CPUC 33% RPS Implementation Analysis

- CPUC commissioned 33% RPS Implementation Analysis as part of long-term procurement planning (LTPP) proceeding
- Goals of analysis:
  - Inform decision-makers about the likely cost and environmental impacts of implementing a 33% Renewables Portfolio Standard by 2020
  - Identify barriers to implementing a 33% RPS by 2020 and most likely timelines for achieving 33%
  - Inform decision-makers about the potential need for new transmission and new resources to integrate intermittent renewables
  - Inform California utilities' 2010 long-term procurement plans
- Report with preliminary results issued June 2009, available at www.cpuc.ca.gov/33percent

2007 Claimed RPS Resources for California Utilities and 2020 RPS Resource Gaps



Note: Gap based on 2007 CEC load forecast minus 2007 claims from CEC Net System Power Report. No adjustments for EE or CHP that is incremental to forecast.

33% RPS Cases Studied

1. **20% RPS Reference Case**: Existing state policy with 20% RPS
2. **33% RPS Reference Case:** Most likely case for reaching 33%, assuming that most contracts signed by IOUs with project developers proceed on schedule
3. **High Wind Case**: Meets 33% RPS resource gap with mix of new resources that includes substantial quantities of wind in California and Baja
4. **Out-of-State Delivered Case**: Meets 33% RPS resource gap with mix of new resources that includes wind resources in California and Wyoming and geothermal resources in Nevada
5. **High DG case**: Meets 33% RPS resource gap with mix of new resources that minimizes the need for new bulk transmission. These include 15,000 MW of distributed solar PV.

33% RPS Reference Case

Cost and Rate Impacts in 2020

- Total CA revenue requirement: ***$54.2 billion (16.9¢/kWh)***
- Incremental to 20% RPS Case: ***+$3.6 billion (+1.1¢/kWh)***
- New transmission investment: ***$12.3 billion***

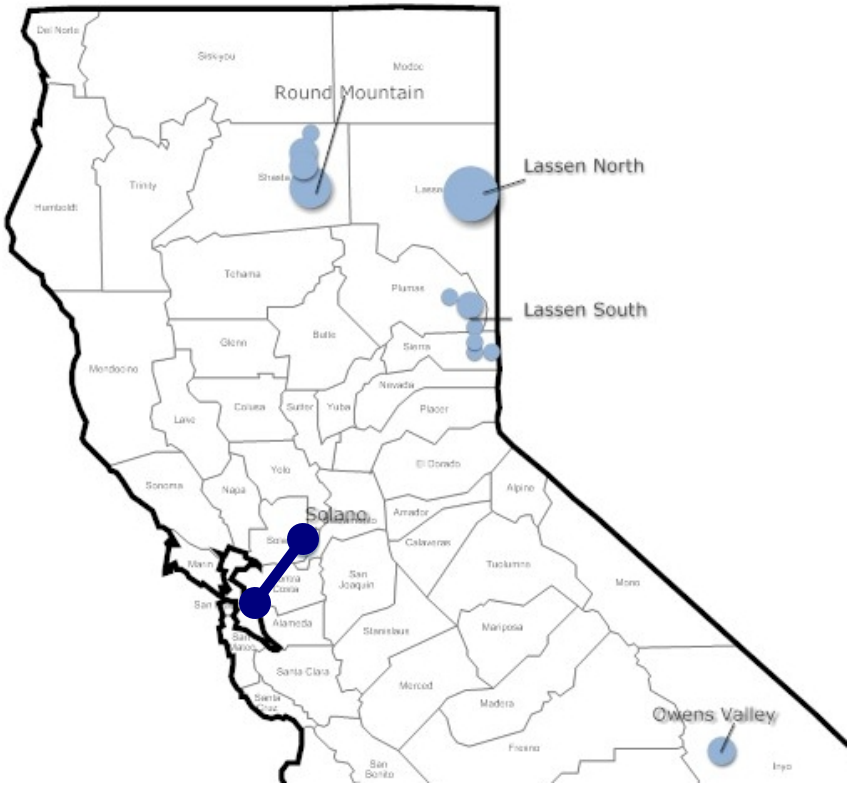
Resources Selected by Type

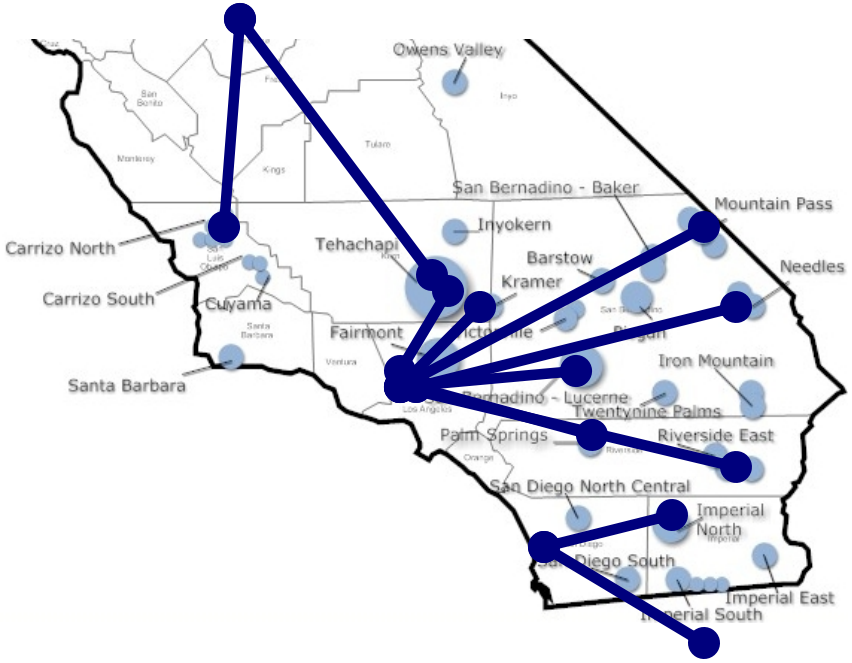
	In-State		Out-of-State		*Total*	
	MW	GWh	MW	GWh	*MW*	*GWh*
Biogas	279	2,078	-	-	*279*	*2,078*
Biomass	391	2,737	87	610	*478*	*3,346*
Geothermal	1,439	11,027	58	445	*1,497*	*11,471*
Hydro - Small	25	111	15	66	*40*	*177*
Solar PV	3,235	6,913	-	-	*3,235*	*6,913*
Solar Thermal	6,764	16,652	534	1,304	*7,298*	*17,956*
Wind	7,573	22,899	3,399	9,809	*10,972*	*32,709*
Total	***19,705***	***62,417***	***4,093***	***12,233***	***23,798***	***74,650***

Zones Selected

	MW	GWh	Notes
Total	***23,798***	***74,650***	
Tehachapi	3,000	8,862	Included in 20% Case
Distributed CPUC Database	525	3,118	Included in 20% Case
Solano	1,000	3,197	Included in 20% Case
Out-of-State Early	2,062	6,617	Included in 20% Case
Imperial North	1,500	9,634	Included in 20% Case
Riverside East	3,000	7,022	Included in 20% Case
Mountain Pass	1,650	4,041	
Carrizo North	1,500	3,306	
Distributed Biogas	249	1,855	
Out-of-State Late	1,934	5,295	
Needles	1,200	3,078	
Kramer	1,650	4,226	
Distributed Geothermal	175	1,344	
Fairmont	1,650	5,003	
San Bernardino - Lucerne	1,800	5,020	
Palm Springs	806	2,711	
Baja	97	321	

New Transmission Required for 33% RPS Reference Case





Interest in High DG Case

- A number of factors drive the CPUC's interest in studying a "High DG" case for meeting 33%:
  - High environmental impact of new transmission
  - High environmental impact of new central station generation
  - Increasing cost competitiveness and customer interest in PV – is PV nearing goal of "grid parity"?
  - Difficulties siting new transmission lines

"If it is conservatively assumed that only 10,000 MW of new high voltage transmission will be built by 2020 to realize the RETI net short target of 68,000 GWh, the estimated cost of this transmission will be in the range of $20 billion in 2008 dollars based on SDG&E's projections for the Sunrise Powerlink. How much thin-film PV located at IOU substations or at the point-of-use on commercial buildings or parking lots could the IOUs purchase for this same $20 billion? ... This equals an installed thin-film PV capacity of 14,000 to 18,000 MW for a $20 billion investment."

Bill Powers, PE, testimony in SDG&E's Sunrise Powerlink CPCN case

Resources Available for Selection in High DG Case

- Resources already selected for 20% Case
- RETI projects that can likely be interconnected without major transmission upgrades
  - Biomass: 2 projects in northern CA, 128 MW of total available capacity
  - Geothermal: 3 projects in northern CA, 175 MW of total available capacity
  - Wind: 6 projects across CA, 468 MW of total available capacity
- Out-of-state resources assumed deliverable over existing transmission (~2000 MW)
- Distributed solar PV resources

2. Identifying Potential Solar PV Sites

BLACK & VEATCH

Overview

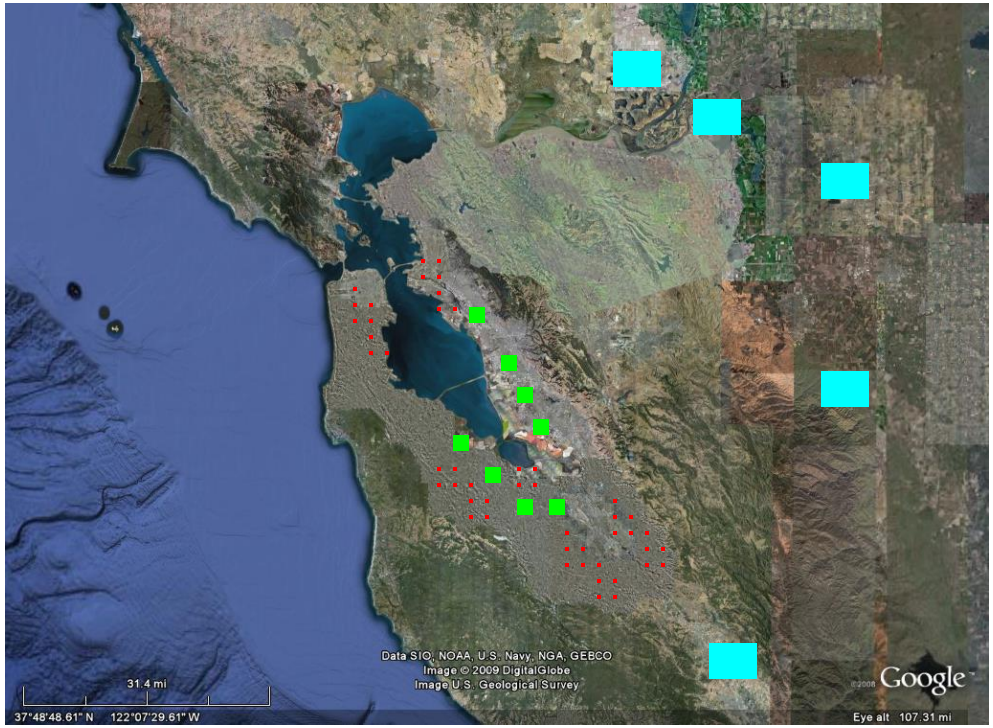
- Solar PV was assumed to be a major technology for DG
- B&V estimated the technical raw potential for DG
- Satellite imagery for rooftops and substation locations for larger utility scale

Distributed Solar PV

- 20 MW sites near non-urban 69 kV substations
- Smaller projects on rooftops, large commercial rooftops with 0.25 MW potential
- Limited by 30% peak load at a given substation

Illustrative Example of Distributed Solar PV

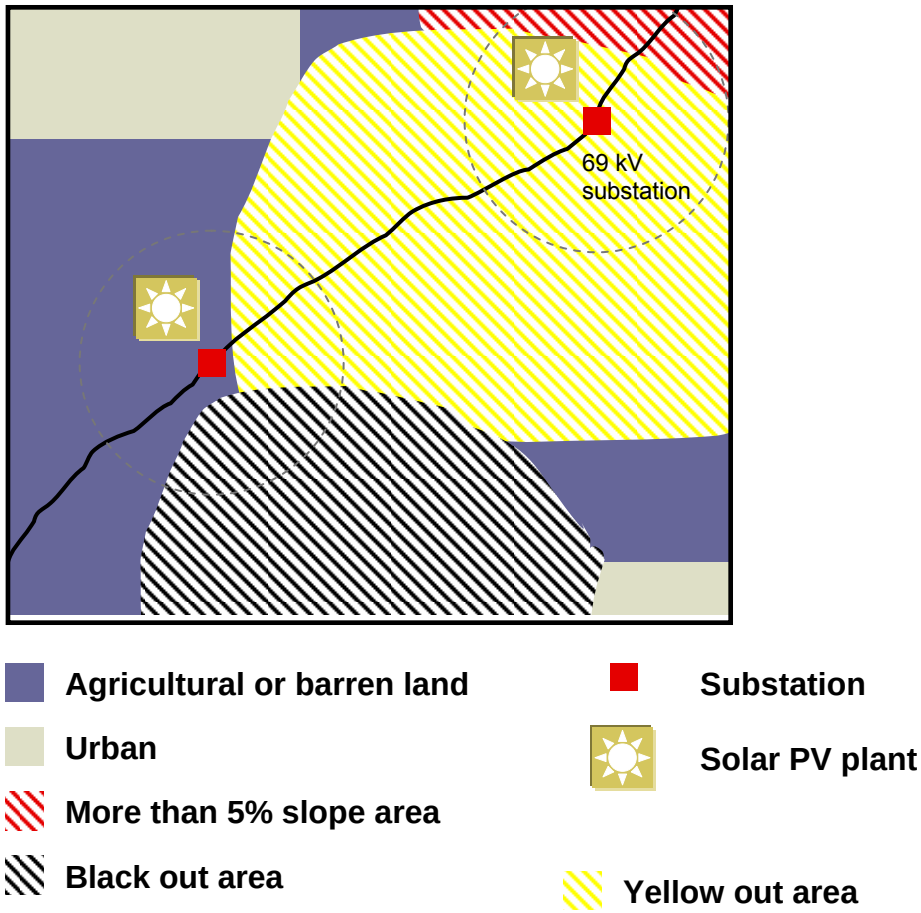
- 20 MW near substations
- Large commercial rooftops
- Residential rooftops



Ground Mounted PV

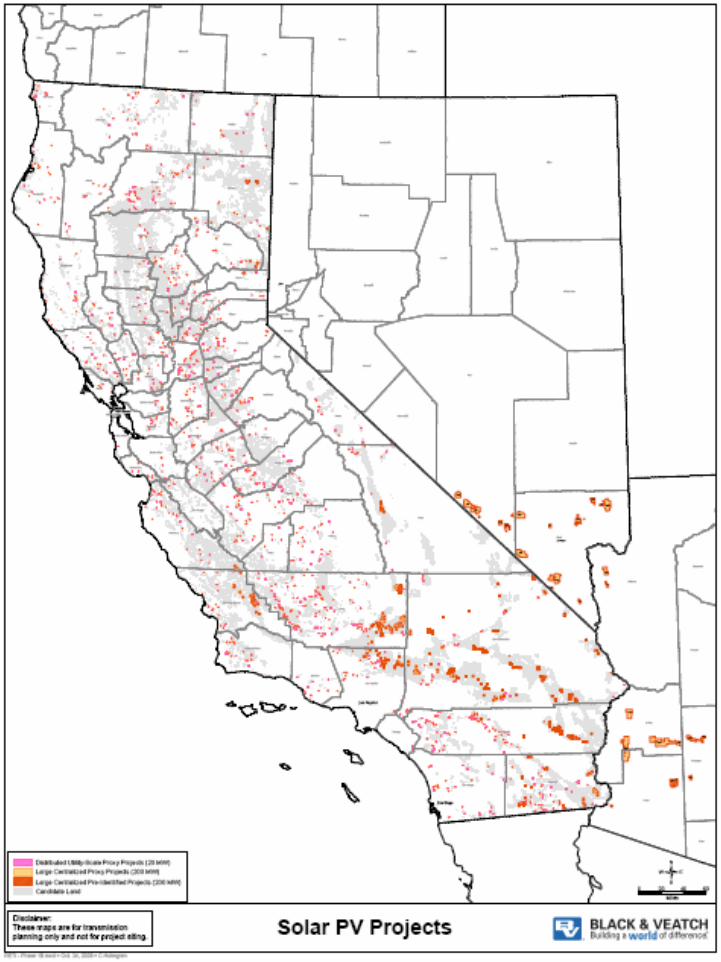
- Initial criteria
  - near sub stations equal or less than 69 kV
  - agricultural or barren land
  - less than 5% slope
- Environmental screen
  - Black out areas
  - Yellow out areas
- Land parcel
  - a continuous 160 acre plot (20 MWp)
  - within 20 miles

Example Map for Solar PV Non-Urban Projects



RETI Results on 20 MW Sites

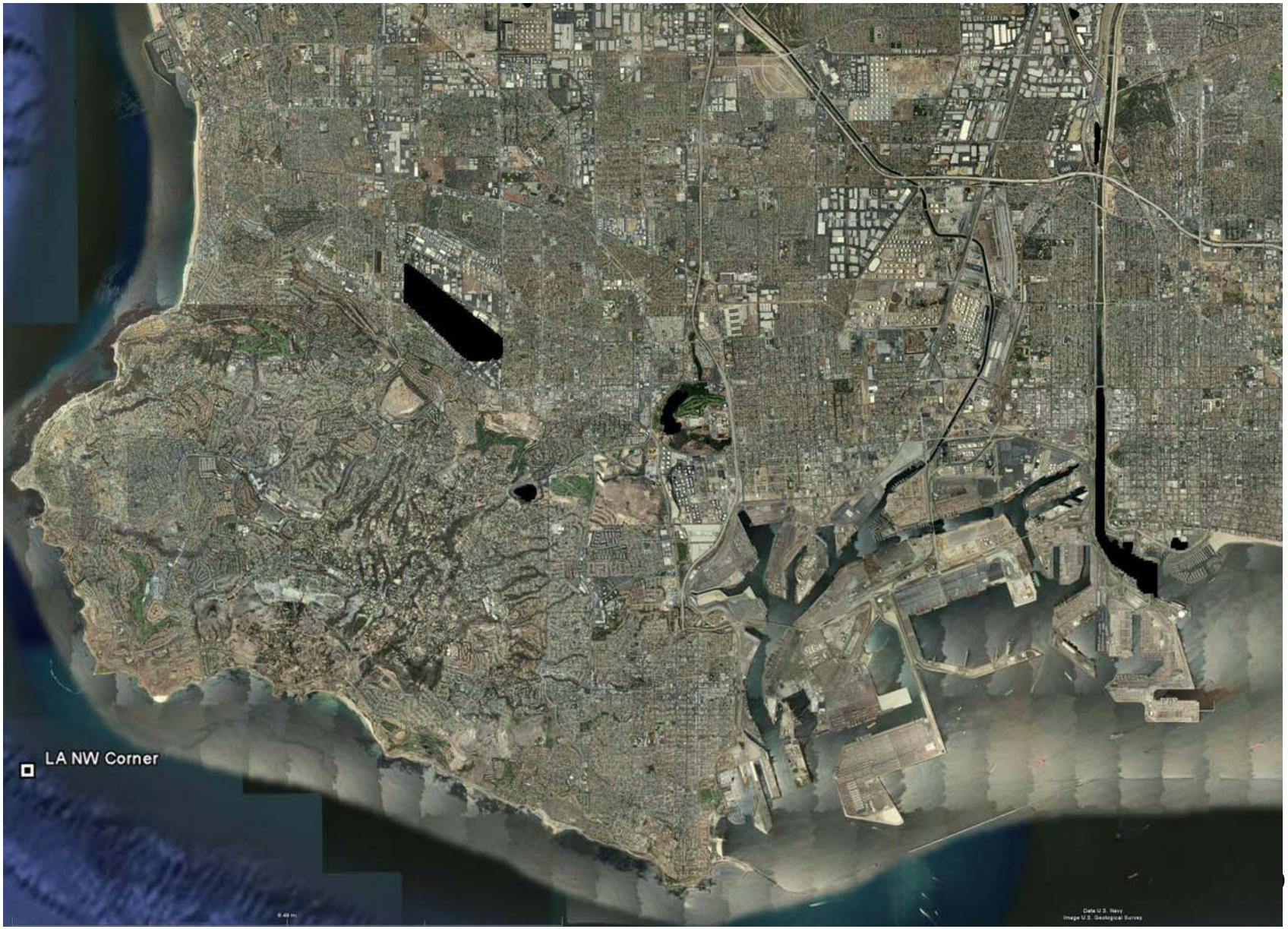
- 27,000 MW nameplate PV sites identified
- ~1300 sites identified
- Filters Applied
  - 160 acres + for 20 MW
  - No sites within 2 miles of urban zones
  - Near substations, most are 2 to 3 miles of the distribution subs with 69kV+ high-side voltage
  - Land slope < 5%
- 20 MW on substations with high side voltage of 69kV
- 40 MW on substations with higher voltage than 69kV
- Assumed not to be Rule 21 compliant



Black and Veatch Rooftop Analysis

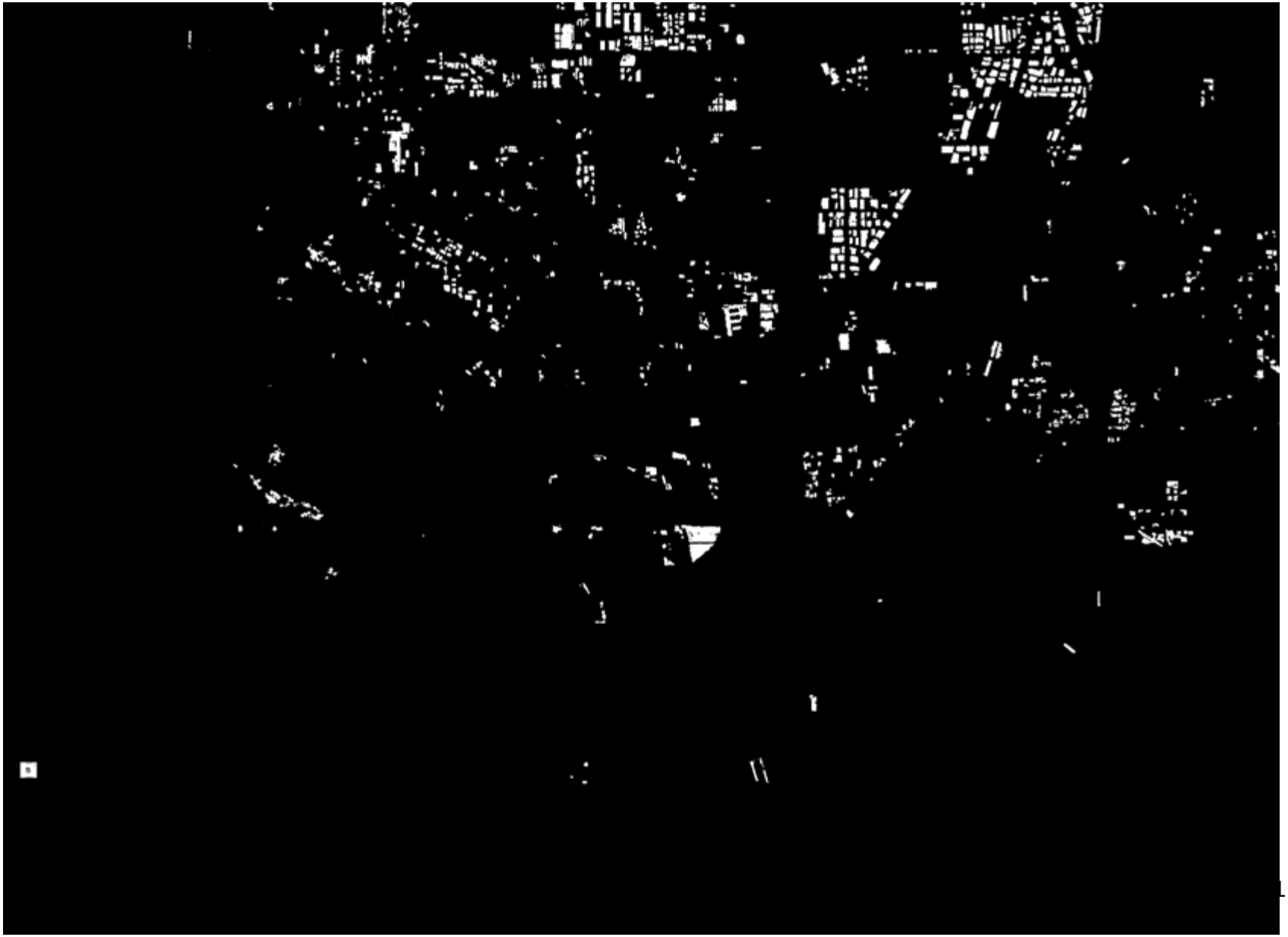
- GIS used to identify large roofs in CA and count available large roof area
- Criteria
  - ‘Urban’ areas with little available land
  - Flat roofs larger than ~1/3 acre
  - Assumes 65% usable space on roof
  - Within 3 miles of distribution substation

Solar Photovoltaic Rooftop Identification

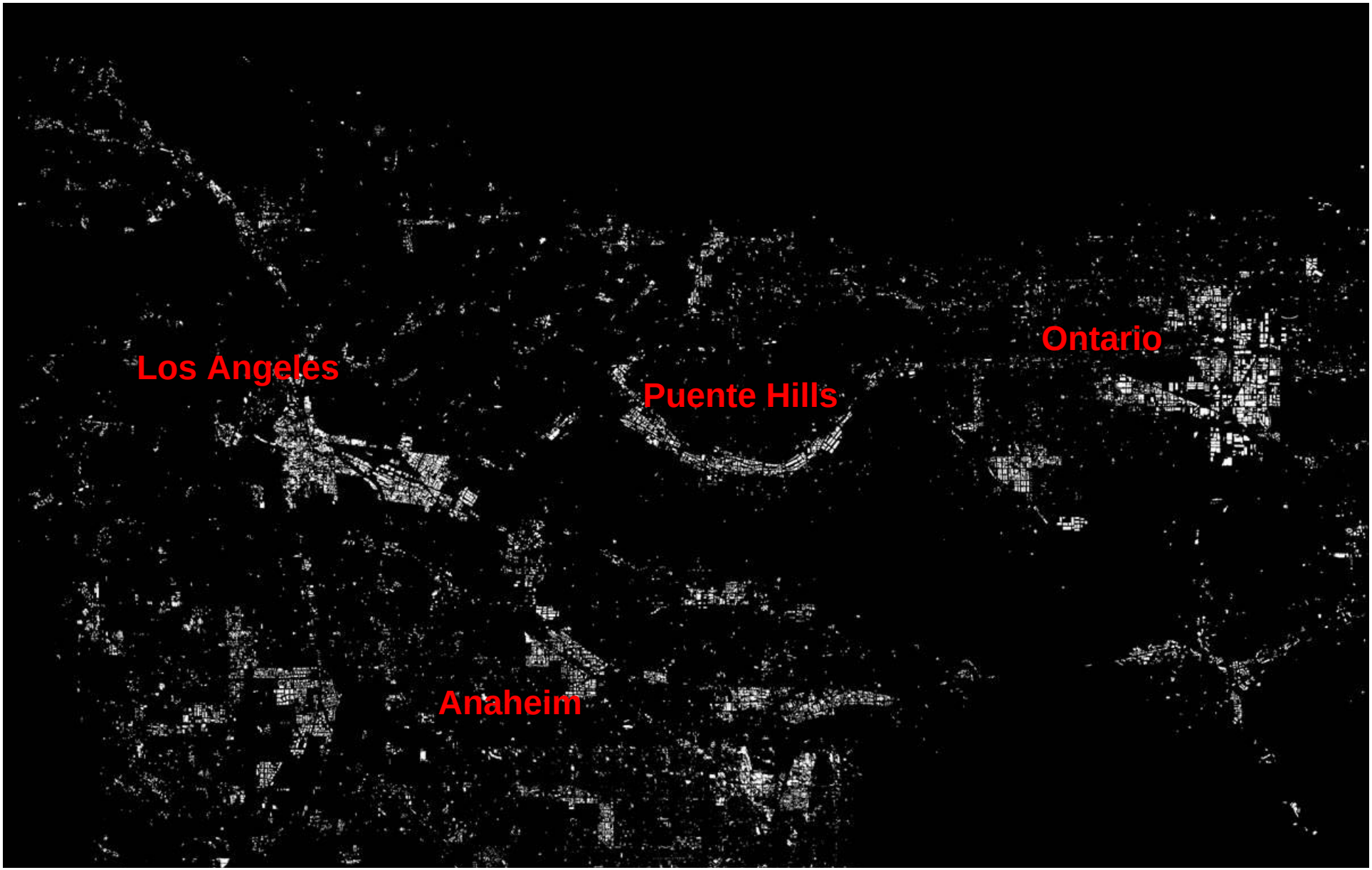


Solar Rooftop Identification

Solar Rooftop Identification

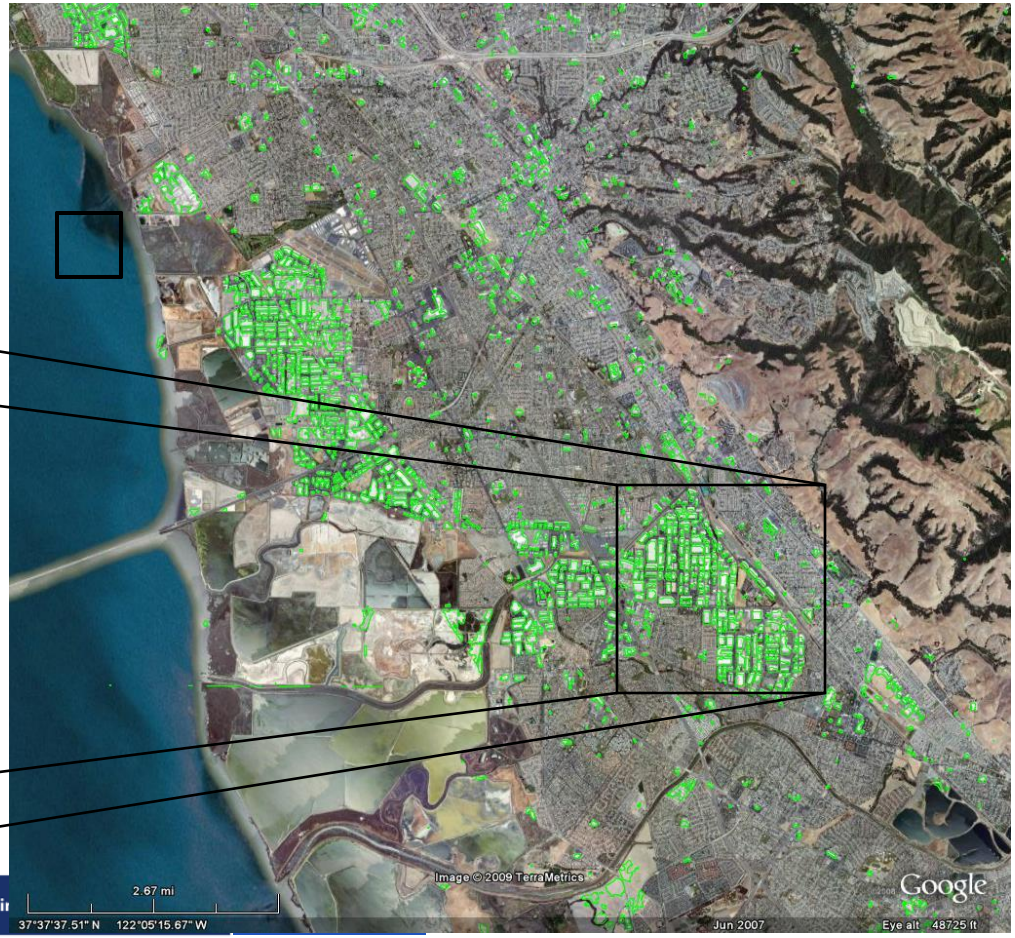


Los Angeles Area “Rooftop Resources”



East Bay Area Example

Analysis automates the counting of roof space and tallies total acreage of large roof space. Also checks proximity to distribution substation (not shown due to confidentiality).



Summary Results for Large Roofs

Raw Potential – Assuming 100% Participation

Total Statewide Large Rooftop Potential

	Large Roof Potential
PG&E	2922 MWac
SCE	5243 MWac
SDG&E	604 MWac
Other	2774 MWac
Total	**11,543 MWac**

3. DG Interconnection Screening

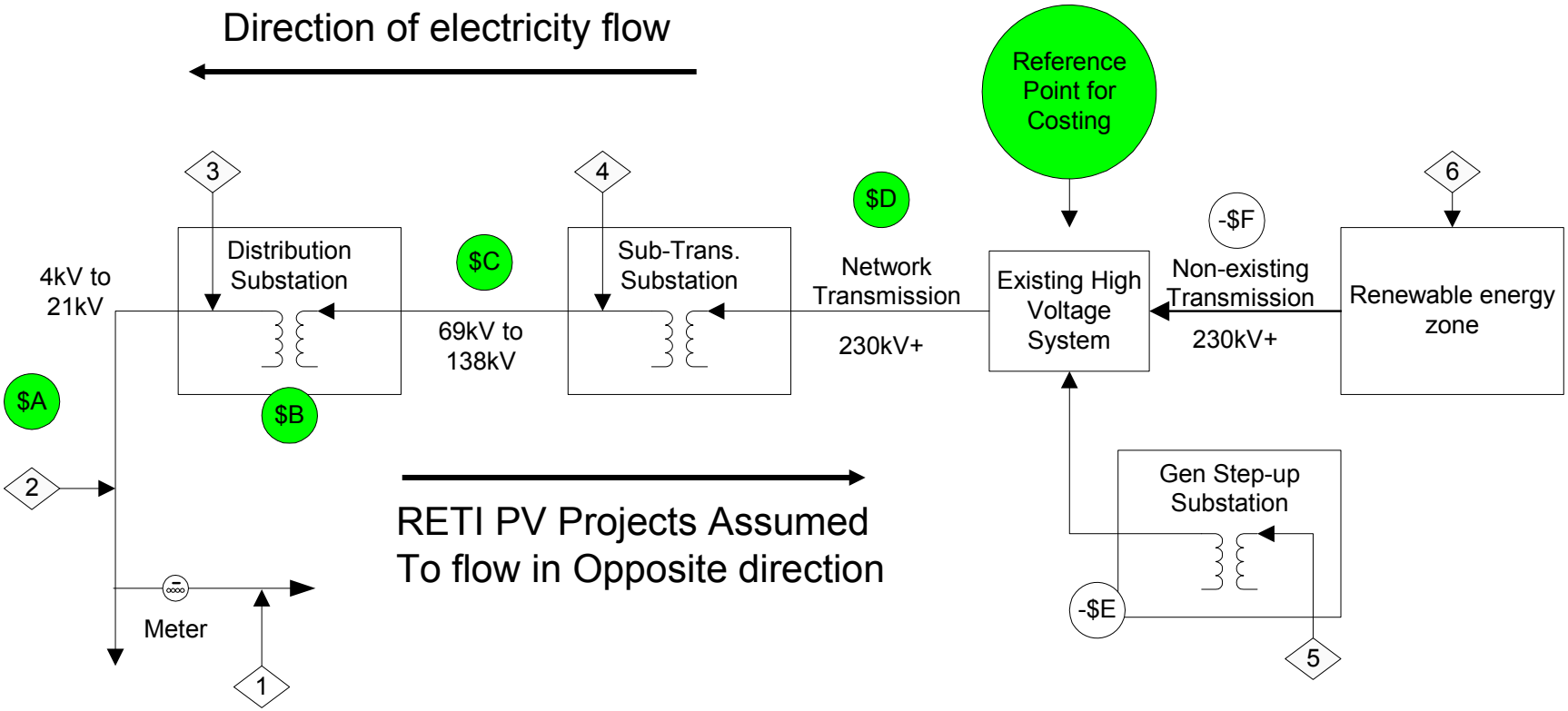
Snuller Price, E3

Energy and Environmental Economics, Inc.

Working Definitions of DG

- Distributed generation (DG) is small-scale generation interconnected at sub-transmission system or lower.
  - Broad definition includes generation that is not necessarily physically close to loads.
- Wholesale DG (WDG) is generation interconnected to the distribution or sub-transmission system
- Customer DG is generation on the customer's side of the meter
  - Does not count toward California's RPS

Diagram of Interconnection Points



Avoided Capacity Cost Assumption

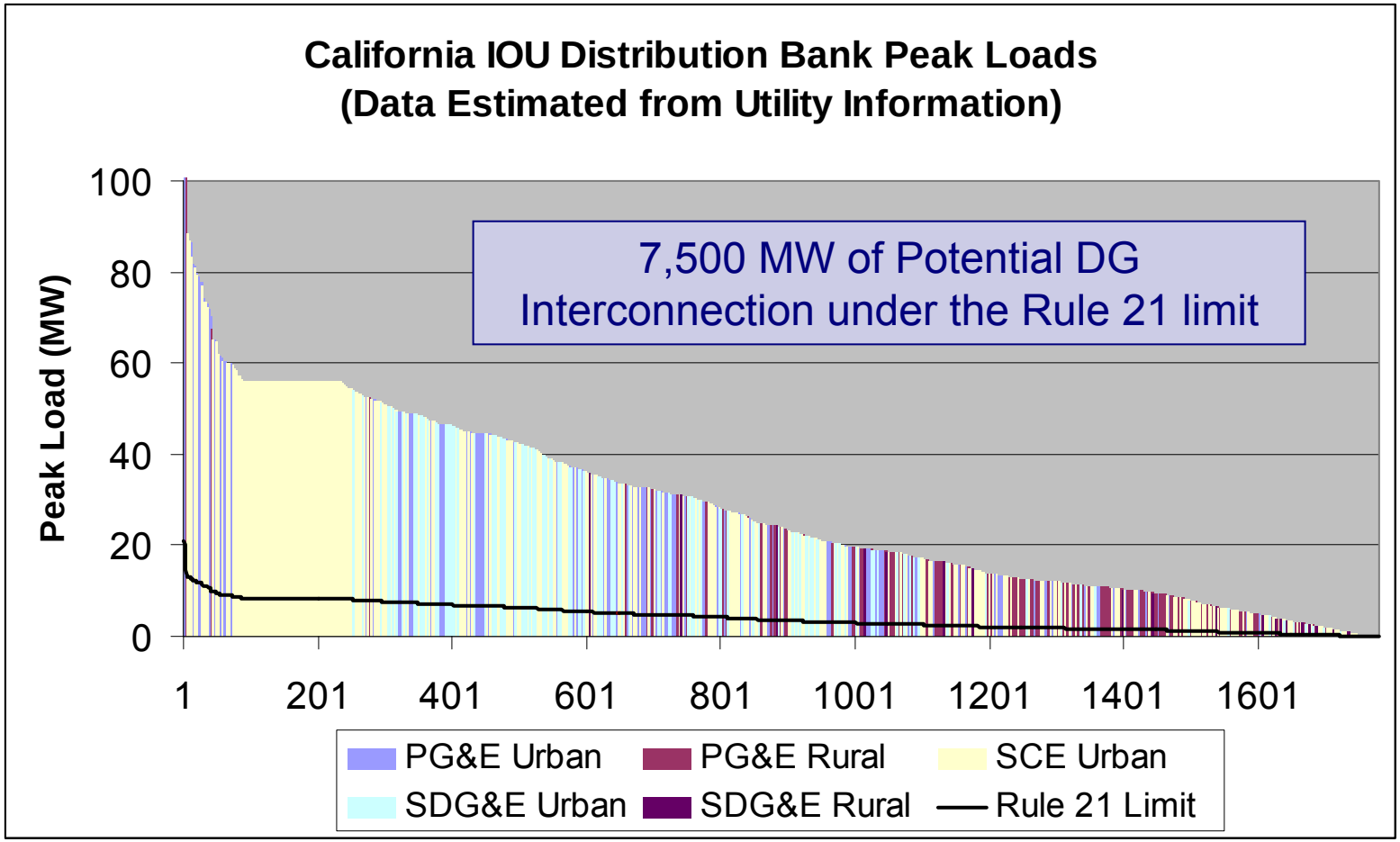
- **Distribution: $34/kW-yr**
  - Used average of EE avoided costs
- **Subtransmission: $34/kW-yr**
  - Used average of EE avoided costs
- **Transmission: $0/kW-yr**
  - Network is more difficult
  - Set to zero for 33% RPS analysis

See EE avoided costs, R.04-04-025

Issues

- Timeframe vs. geographic specificity – must use long time frame for avoided cost value
- Cost of non-Rule 21 RETI 20MW PV Installations not studied
  - Network transmission costs of $65/kW-year assumed for these resources

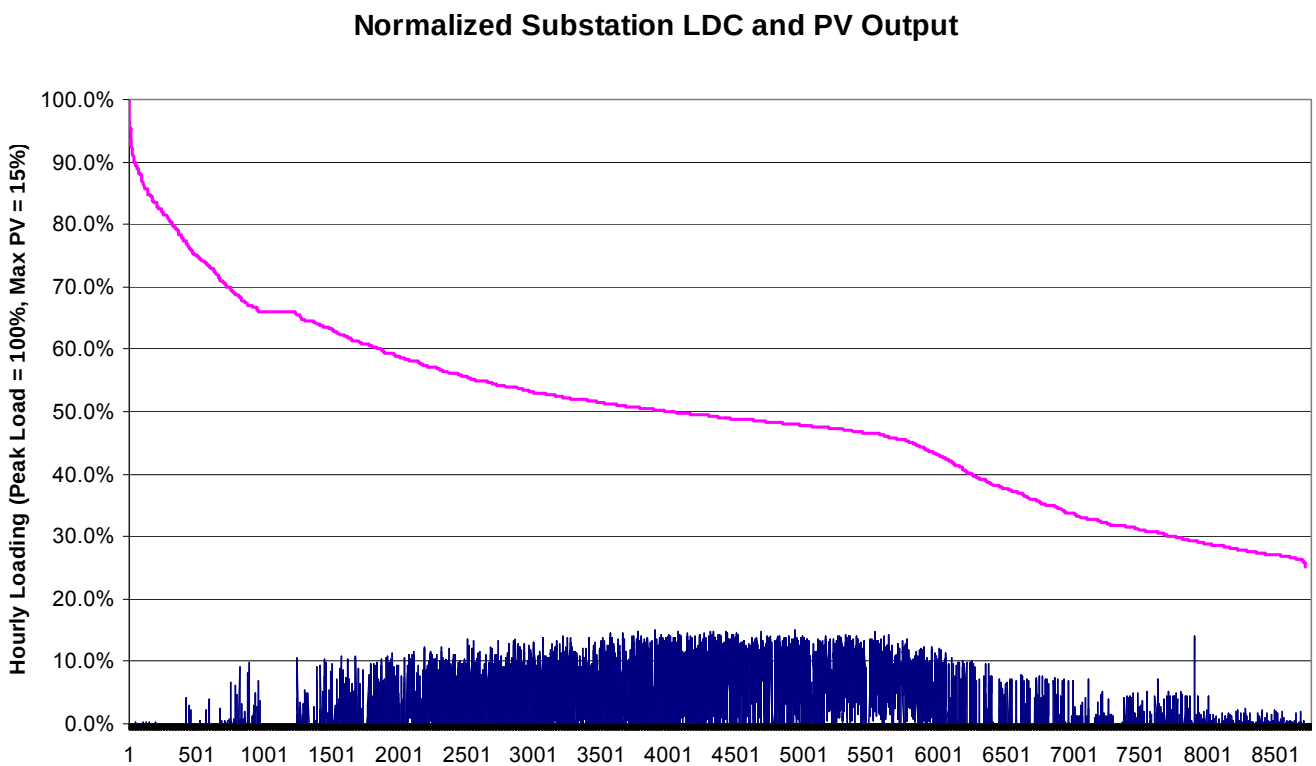
Utility Substation Bank Data



Rule 21 Interconnection sets 15% of line section peak limit

Revisit 15% threshold for some PV projects, given higher PV output at higher load levels

- Load Duration Curve compared to PV output

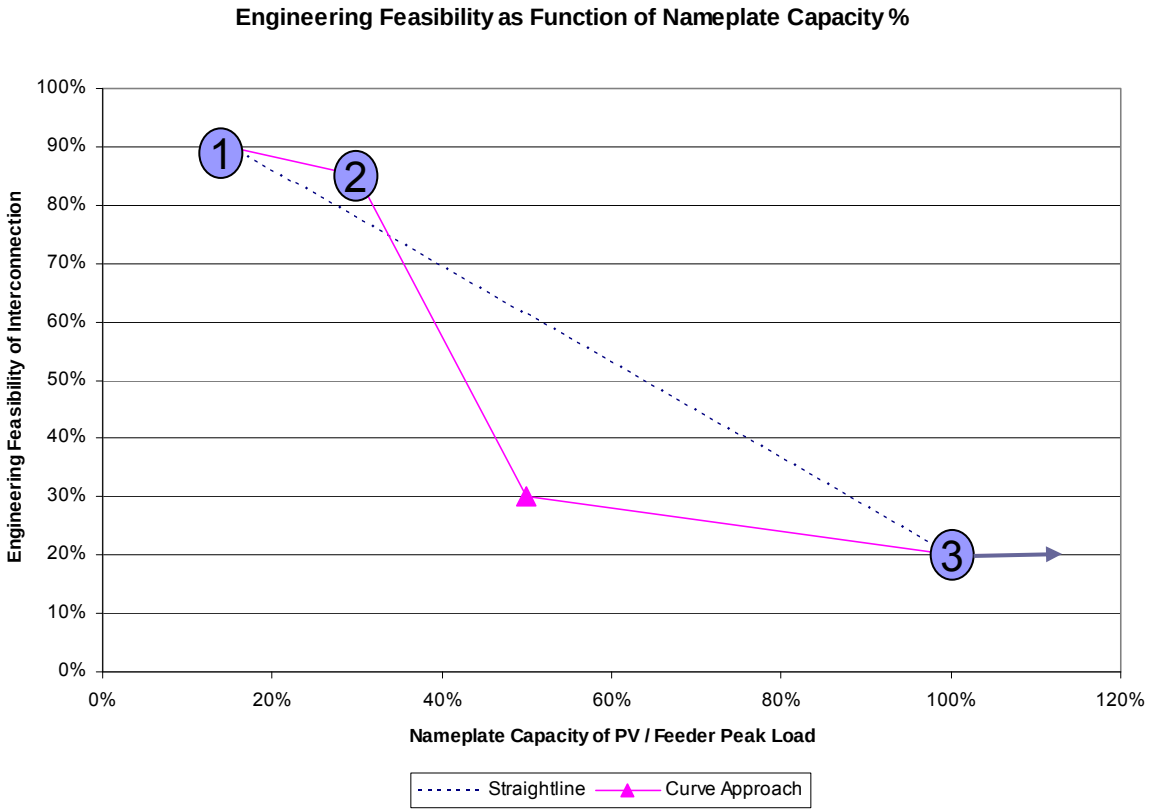


Actual data from a California public utility substation and PV installation

Technical Feasibility of PV Connections that are >15% & <100% of Peak Load

- Assumption on PV engineering feasibility

Caveat
These numbers are based on an educated guess not on any engineering analysis.

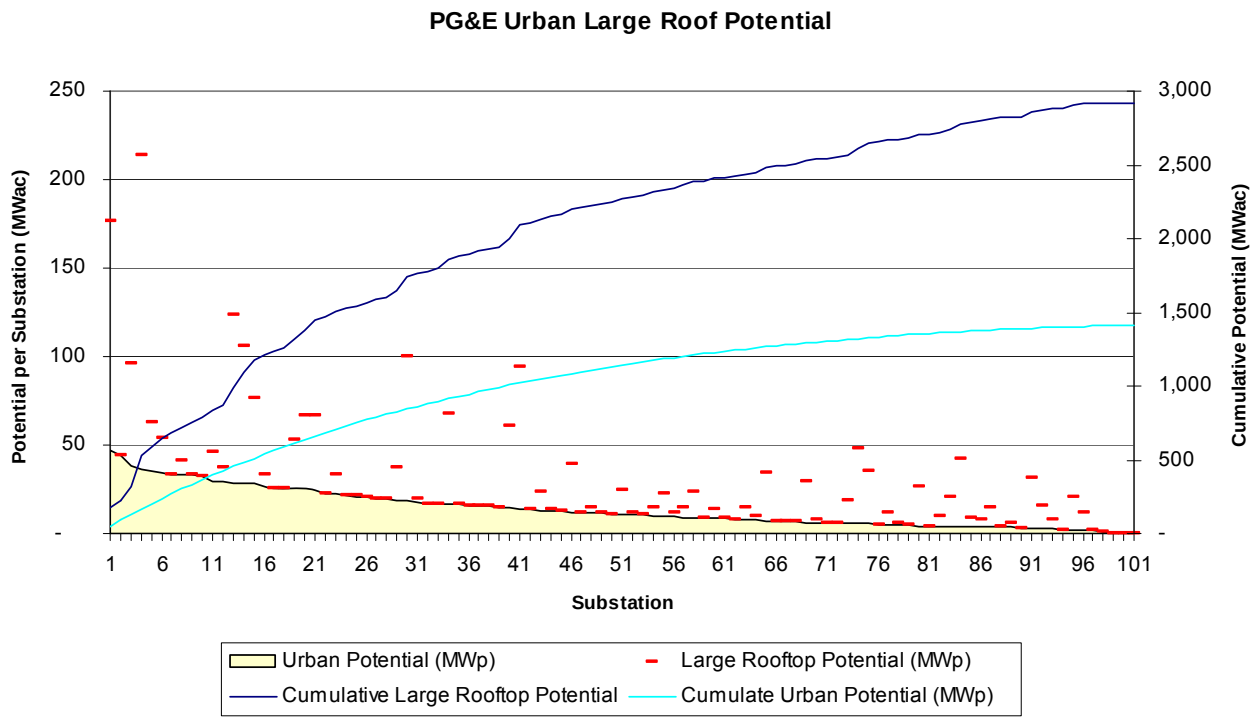


1 15% Peak Load
50% of in area PV

2 30% Peak Load
50% of in area PV

3 100+% Peak Load
RETI projects

PG&E Example – Bay Area



Clusters of large roofs make it impossible to do every roof and be below the 30% peak load.

PV Screening Criteria

	Land / Roof Availability	Interconnection	Participation
Urban Large Roofs	GIS Screening	Within 3 miles of substation, limited to 30% bank or feeder peak	33% Roofs max
Urban Small Roofs	Assumed available	30% bank or feeder peak	33% Roofs max
Rural <20MW	GIS Screening	30% bank or feeder peak	33% available land max
Rural >20MW	GIS Screening	Not constrained, but assigned interconnection cost of $68/kW-year	33% available land max

Total PV Availability for High DG Case by Type and Utility

Installed Capacity by PV System Type (MWac)

Utility	Ground Mounted (> 30%)	Ground Mounted	Large Roofs	Small Roofs	Total
PG&E	3,153	665	943	758	**5,519**
SCE	2,878	1,011	1,592	586	**6,067**
SDG&E	552	255	218	380	**1,406**
Other	2,417	335	1,057	500	**4,309**
Total	**9,000**	**2,266**	**3,810**	**2,224**	**17,300**

Other WDG Resources

- Biogas/Biomass
  - Resource potential developed based on discussion with stakeholders
  - Constrained by fuel availability
  - Total available capacity of 250 MW of Biogas, 35 MW of distribution-connected Biomass

Statewide DG Potential by Type

Nameplate MW	DG Type					
Connection	Biogas	Biomass	Geothermal	Solar PV	Wind	Total
1. Customer Site	-	-	-	2,224	-	2,224
2. Feeder	249	34	-	3,810	-	4,093
3. Distribution Bank	-	-	-	2,267	-	2,267
4. Subtransmission	-	128	175	9,000	468	9,771
Total	249	162	175	17,301	468	18,355

4. Results and Final Thoughts

High DG Case Results

- Case constructed to minimize the need for new transmission corridors
- Start from 20% case
- Replace central station solar and wind with 15,000 MW of mostly distributed solar PV

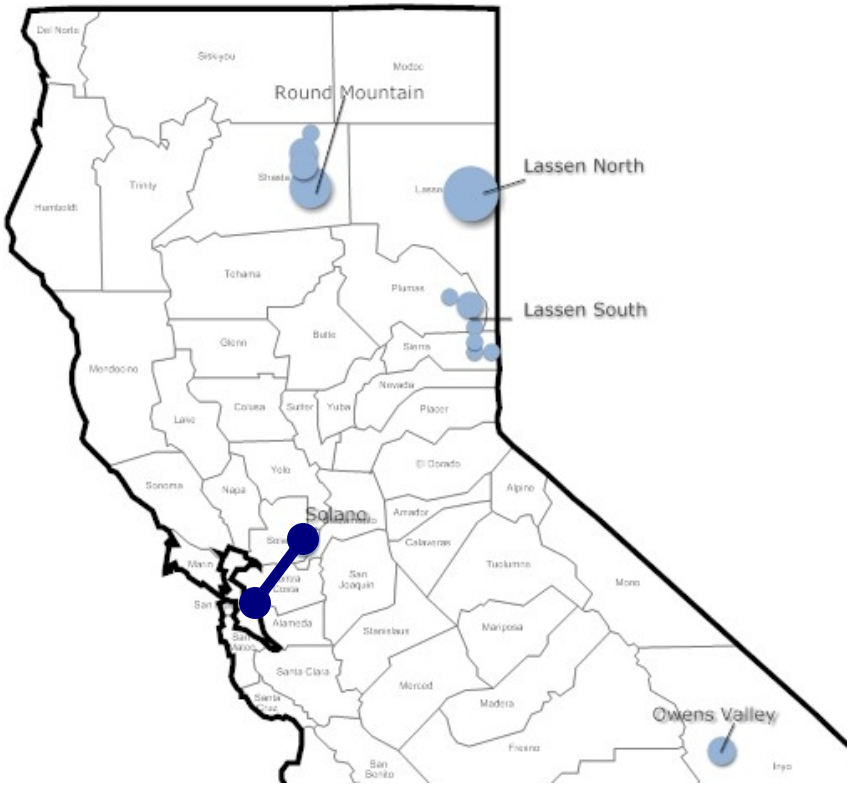
Zones Selected

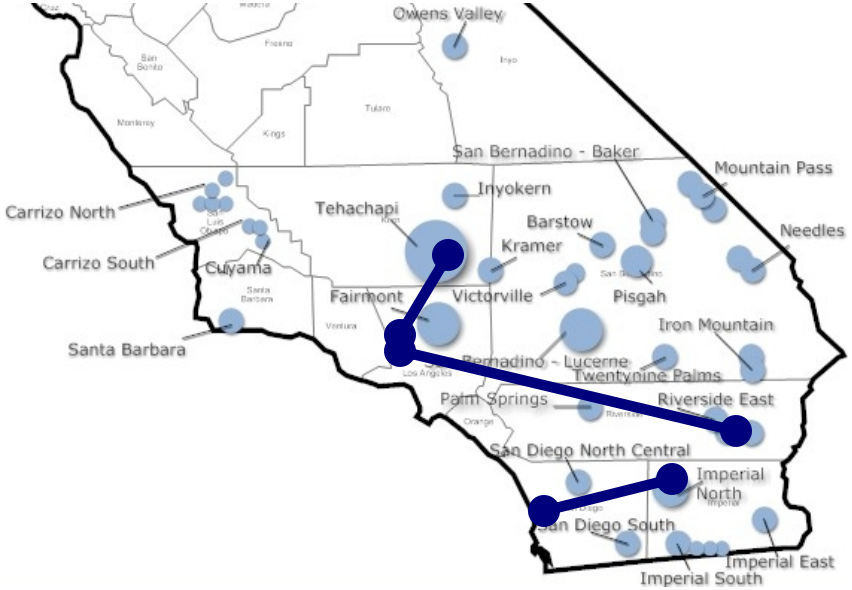
	MW	GWh	Notes
Total	*26,761*	*74,650*	
Tehachapi	3,000	8,862	*Included in Reference Case*
Distributed CPUC	525	3,118	*Included in Reference Case*
Solano	1,000	3,197	*Included in Reference Case*
Out-of-State Early	2,062	6,617	*Included in Reference Case*
Imperial North	1,500	9,634	*Included in Reference Case*
Riverside East	1,500	3,507	*Included in Reference Case*
Distributed Biogas	249	1,855	
Distributed	175	1,344	
Distributed Wind	468	1,289	
Out-of-State Late	1,934	5,295	
Distributed Biomass	162	1,138	
Remote DG	9,000	19,236	
Distributed Solar	5,186	9,558	

Resources Selected by Type

	In-State		Out-of-State		*Total*	
	MW	GWh	MW	GWh	*MW*	*GWh*
Biogas	279	2,078	-	-	*279*	*2,078*
Biomass	403	2,825	87	610	*490*	*3,435*
Geothermal	1,415	10,859	58	445	*1,473*	*11,303*
Hydro - Small	22	95	15	66	*37*	*161*
Solar PV	15,068	30,678	-	-	*15,068*	*30,678*
Solar Thermal	1,095	2,674	534	1,304	*1,629*	*3,978*
Wind	4,484	13,529	3,302	9,488	*7,785*	*23,017*
Total	*22,765*	*62,738*	*3,996*	*11,912*	*26,761*	*74,650*

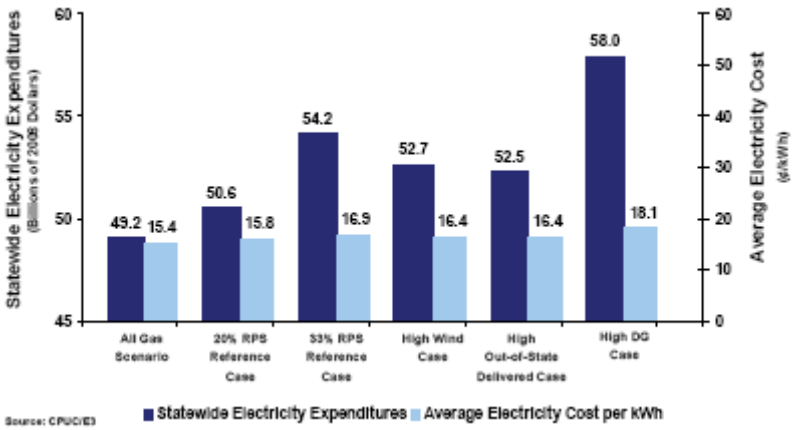
New Transmission Required for High DG Case





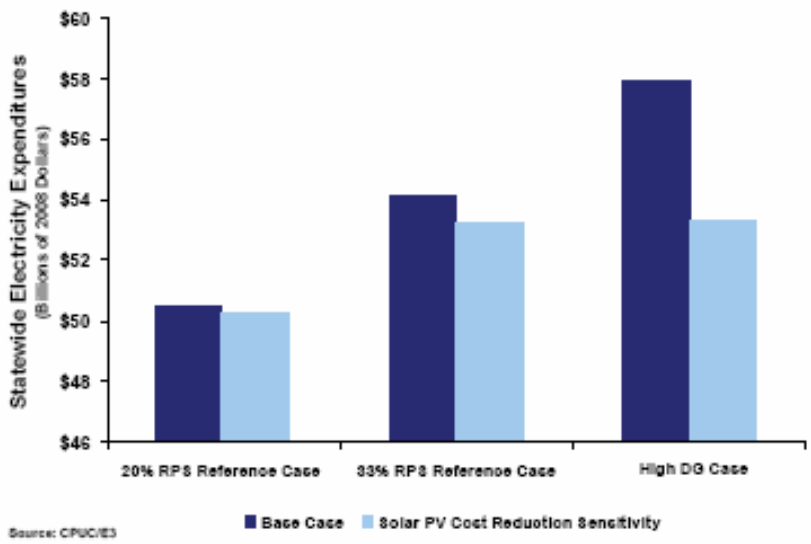
Cost Impacts of 33% RPS Cases

- Incremental cost of 33% Ref. Case in 2020:
  - +$3.6 billion relative to 20% RPS
  - Average retail rate: 16.9¢/kWh
  - 7% increase relative to 20% RPS
- Incremental cost of High DG Case in 2020:
  - +$3.8 billion relative to 33% Ref Case
  - +$7.4 billion relative to 20% RPS
  - Average retail rate: 18.1¢/kWh
  - 14.6% increase relative to 20% RPS



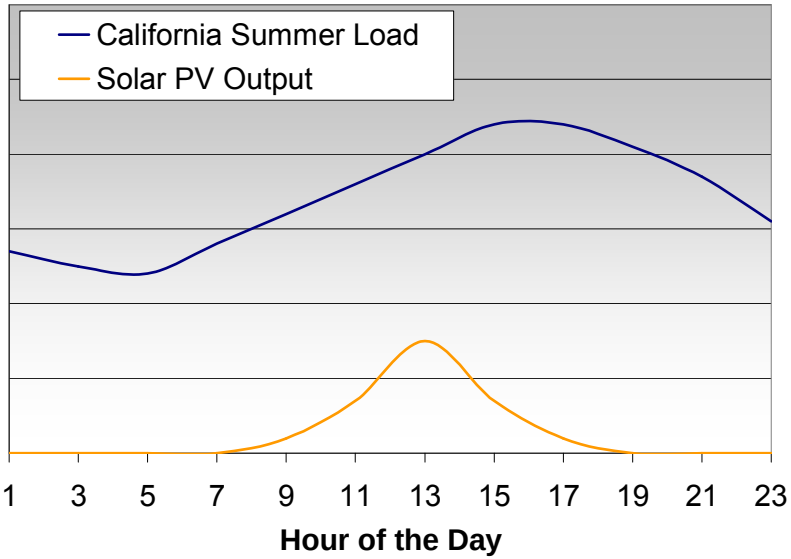
Solar PV Cost Reduction Sensitivity

- Delivered PV costs have come down substantially in the last year, and further reductions can be expected as the industry scales up
- We conducted a sensitivity analysis by reducing installed cost of PV from $7/We to $3.70/We
  - Price point developed for RETI to be in line with industry targets
  - Reduces levelized cost of PV from $306/MWh to $168/MWh
  - High DG case is similar in cost to 33% Reference Case



Final Thoughts and Next Steps

- We were not able to eliminate *all* transmission lines – assumed lines already approved go forward
- Much additional work could be done to refine the distributed PV potential estimates
- All cases assume indefinite continuation of current federal and state tax incentives
- We did not do any analysis on operations issues associated with high PV build
  - Ability of grid to absorb energy at PV output profile
  - Voltage and grid stability issues associated with lack of inertia
  - CAISO is now studying integration requirements of all 33% cases



California Public Utilities Commission

33% RENEWABLES PORTFOLIO STANDARD
Implementation Analysis Preliminary Results

June 2009

Prepared by:

California Public Utilities Commission

PAUL DOUGLAS
Project Lead
RPS Program and Project Supervisor

ELIZABETH STOLTZFUS
Project Manager

ANNE GILLETTE
JACLYN MARKS
Lead Authors

Technical Analysis by:

Energy and Environmental Economics, Inc.
Aspen Environmental Group

Special Thanks to:

ARNE OLSON – Energy and Environmental Economics
SUSAN LEE – Aspen Environmental Group
SIMON EILIF BAKER – CPUC

Acknowledgements

This report is the product of collaboration between the California Public Utilities Commission (CPUC) Energy Division staff and a team of consultants. The CPUC Project Lead was Paul Douglas, and the Project Manager was Elizabeth Stoltzfus. The CPUC team also included Anne Gillette, Jaclyn Marks, and Simon Baker. We would like to emphasize that the views and analyses expressed in this report are not the views of the CPUC, but rather the contributors to this report.

We are grateful for the technical analysis and expertise that the consultants provided to this effort. In particular, we would like to thank Arne Olsen, Ren Orans, Snuller Price, Amber Mahone, and Doug Allen from Energy Environmental Economics, Inc., and Carl Linvill, Susan Lee, and Brewster Birdsall of Aspen Environmental Group, the primary consultant study team. We would also like to thank Eric Toolson and Wenxiong Huang from PLEXOS Solutions, LLC., and Tim Mason, Ryan Pletka, and Derek Djeu from Black and Veatch.

In addition to the consulting team, we would like to thank Gary DeShazo, Grant Rosenblum, and Judith Sanders from the California Independent System Operator for their technical input throughout the analysis and for their future contribution to Phase 3 of this analysis.

The staff at the CPUC contributed significantly to validating the technical analysis as well as reading through various drafts of this report. We are especially grateful to our management, Julie Fitch and Nancy Ryan for their continued guidance and support in helping to craft this report. We would also like to thank Dan Hartmann and Amy Baker for the graphics, and Simon Baker for supporting this effort since its inception a year ago. Our report also benefited from careful editing and review from other colleagues at the CPUC, including Kristin Ralff-Douglas, Keith White, Pete Skala, Molly Sterkel, Billie Blanchard, Chloe Lukins, Burt Mattson, Anne Simon, Victoria Kolakowski, Janet Econome, Peter Allen, Sara Kamins, and Iain Fisher. We would also like to thank Terrie Prosper for copy editing this report.

Lastly, we would like to thank the participants of the 33% RPS Implementation Analysis Working Group and the Transmission Constrained Working Group in the long-term procurement plans proceeding who provided their technical expertise through attending workshops, working group meetings, conference calls, and technical comments.

Contents

1. Executive Summary 1

2. Introduction 12

3. 33% RPS Resource Portfolio Results 17

4. 33% RPS Reference Case Illustrative Timelines 33

5. Summary of 33% RPS Cases 56

6. Findings 60

Appendix A: *List of Acronyms* 65

Appendix B: *Methodology* 67

Appendix C: *Resource Zones and Resource Mix for each Renewable Case* 83

Tables

Table 1. Data Sources Used in 33% RPS Implementation Analysis 18

Table 2. 2020 Cases Developed for the 33% RPS Implementation Analysis 19

Table 3. New Renewable Resources Required to Meet a 33% RPS by 2020 in TWh 19

Table 4. Locations of Renewable Resource Zones in 33% RPS Reference Case 21

Table 5. Projected California Electricity Costs in 2020 (billions of 2008 dollars)..... 22

Table 6. Costs and Cost Differences Between Alternative RPS Cases in 2020 24

Table 7. Assumptions in the 33% RPS Implementation Analysis Reference Cases Compared to the Low-Load Sensitivity..... 28

Table 8. Statewide Electricity Expenditures in 2020 for the 20% and 33% RPS Reference Cases Under the Low-Load Sensitivity (billions of 2008 dollars)..... 29

Table 9. 2020 Capacity Balance Under the 20% and 33% RPS Reference Cases for the Base Case and Low-Load Sensitivity Load Growth (MW)..... 30

Table 10. Renewable Resource Zones that Need New Transmission for 20% and 33% RPS Reference Cases 34

Table 11. Permitting Jurisdiction for Generation Projects in the 33% RPS Reference Case 35

Table 12. Description of Illustrative Timelines for the 33% RPS Reference Case 38

Table 13. Cumulative Statewide Capital Investment Required Through 2020 Under the 20% and 33% RPS Reference Cases (billions of 2008 dollars)..... 53

Table 14. Comparison of 33% RPS Cases Across RPS Policy Objectives 59

Table 15. Sample Renewable Procurement Options Based on Policy Priorities..... 61

Table 16. Screens and Criteria to Estimate Urban Solar PV Potential 71

Table 17. High Level Distributed Renewable Technical Potential..... 72

Table 18. Environmental Permitting Risks Factored into Renewable Project Rankings 74

Table 19. Cost Metrics..... 75

Table 20. Assumptions in all 2020 Cases 77

Table 21. Generic Timeline for an IOU-Owned Transmission Line > 200 kV, Based on Past Transmission Permitting Experience 80

Table 22. Generic Renewable Generation Timeline for an IOU-Contracted Resource 81

Figures

Figure 1. Renewable Resource Mixes in 2020 under Different Cases 20
Figure 2. Statewide Electricity Expenditures and Average Electricity Cost in 2020 24
Figure 3. Impact of Gas and CO_2 Allowance Prices on Statewide Expenditures 26
Figure 4. Cost Savings Due to Solar PV Cost Reduction Sensitivity 32
Figure 5. Process for Developing 33% RPS Reference Case Timelines 33
Figure 6. Example of Generation and Transmission Timelines Combined to Create a Resource Zone Timeline 37
Figure 7. Illustrative Timeline 1 for the 33% RPS Reference Case: Historical Experience Without Process Reform 41
Figure 8. Illustrative Timeline 2A for the 33% RPS Reference Case: Current Practice With Process Reform and No External Risks 43
Figure 9. Illustrative Timeline 2B for the 33% RPS Reference Case: Current Practice With Process Reform and External Risks 49
Figure 10. Annual Renewable Generation Buildout for Timelines 2A and 2B 50
Figure 11. Global and Statewide Installed Capacity Versus Installed Capacity of 33% RPS Reference Case in 2020 51
Figure 12. 33% RPS Implementation Analysis Study Flow Chart Depicting Phases 1-3 69
Figure 13. Developer Levelized Cost of Generation by Technology Type 73
Figure 14. Timeline Development Flow Chart 79
Figure 15. Standard Permitting Timelines for Categories of Renewable Generation Projects ... 82
Figure 16. Standard Construction Timelines for Categories of Renewable Generation Projects 82

1 Executive Summary

California lawmakers are currently developing legislation to increase the current 20% by 2010 Renewables Portfolio Standard (RPS) to 33% by 2020. The California Public Utilities Commission (CPUC) and California Energy Commission (Energy Commission) have endorsed this change and it is a key greenhouse gas (GHG) reduction strategy in the California Air Resources Board's (ARB) Assembly Bill (AB) 32 Scoping Plan. As the principal agency responsible for implementing the current RPS program, the CPUC has learned many lessons that can help guide the design of a higher mandate. In addition, several recent analyses have cast light on various aspects of renewable energy development and integration. Drawing on these resources and new analyses, staff at the CPUC developed this report in order to provide new, in-depth analysis on the cost, risk, and timing of meeting a 33% RPS. This report does not recommend a preferred strategy on how to reach a 33% RPS, but rather provides an analytical framework for policymakers to weigh the tradeoffs inherent in any future 33% RPS program for California.

Summary of key findings include:

- **Timeline:** Achieving 33% RPS by the year 2020 is highly ambitious, given the magnitude of the infrastructure buildout required.
- **Resources:** To meet the current 20% RPS by 2010 target, four major new transmission lines are needed at a cost of $4 billion. Three of these lines are already underway. To meet a 33% RPS by 2020 target, seven additional lines at a cost of $12 billion would be required. In addition, the 33% RPS target is projected to require almost a tripling of renewable electricity, from 27 terawatt hours (TWh) today to approximately 75 TWh in 2020.
- **Cost:** Electricity will be higher in 2020 regardless of the RPS requirements.
    - Even if California makes no further investments in renewable energy, this analysis projects that average electricity costs per kilowatt-hour will rise by 16.7% in 2020 compared to 2008 in real terms.
    - In 2020, the total statewide electricity expenditures of achieving a 20% RPS are projected to be 2.8% higher compared to a hypothetical all-gas scenario, where new electricity needs are met entirely with natural gas generation.
    - In 2020, the total statewide electricity expenditures of achieving a 33% RPS utilizing the current procurement strategy is projected to be 7.1% higher compared to the 20% RPS, and 10.2% higher compared to an all-gas scenario.
- **Policies:** Achieving a 33% RPS by 2020 requires tradeoffs amongst various policy goals and objectives. If the 2020 timeline is the most important policy priority, California must start implementing mitigation strategies such as planning for more transmission and generation than is needed to reach just 33%, pursuing procurement that is not dependent on new transmission, or concentrating renewable development in pre-permitted land that would be set aside for a renewable energy park.

APPROACH

Four Unique Renewable Resource Cases Created for Analysis

In order to conduct the implementation analysis, four unique renewable resource cases were developed. Each case represents a different 33% RPS procurement strategy to reaching the 33% RPS target. All cases assume current statutorily defined out-of-state deliverability requirements for renewables into California. Thus, these cases cannot be used to analyze the option of allowing out-of-state tradable renewable energy credits (REC) with no delivery requirement for RPS compliance.

- **33% RPS Reference Case:** This case represents California's current renewable procurement path, which is heavily dependent on new technologies, such as central station solar thermal.
- **High Wind Case:** This case demonstrates less reliance on in-state solar thermal and more reliance on less expensive wind resources in California and the Mexican state of Baja California.
- **High Out-of-State Delivered Case:** This case relies on construction of new, long-line, multi-state transmission to allow California utilities to procure large quantities of low-cost wind and geothermal resources from other western states (as noted above, this case does not include the use of tradable RECs with no delivery requirement).
- **High Distributed Generation (DG) Case:** This case assumes limited new transmission corridors can be developed to access additional renewable resources needed to achieve a 33% RPS. Instead, extensive, smaller-scale, renewable generation is interconnected to the distribution system or close to transmission substations.

In addition, a **20% RPS Reference Case** was developed to serve as a benchmark for cost comparisons between the cost of the current 20% RPS program and a 33% RPS in 2020. This reference case is comprised of California's likely renewable energy mix in 2020 based upon current state law and existing RPS contracts. As such, this case provides the most relevant benchmark against which to measure the incremental cost of various paths to meeting the higher 33% RPS target.

Two additional scenarios were developed to provide further points of reference:

- **All-Gas Scenario:** This scenario represents the resource mix in 2020 if no additional renewables were developed beyond 2007, and the rest of California's electricity needs were met with gas-fired generation. It supports comparisons between the cost of continuing investments in mostly natural gas and implementing a 33% RPS in 2020.
- **2008 Costs:** This scenario represents the current cost of electricity in California. It supports comparisons across the 2020 scenarios of increases relative to today's costs.

The report uses the four different possible 33% RPS cases to assess the costs and tradeoffs of each approach. It should be noted that:

- Projected costs are based on renewable technology costs and not the contract prices.
- The cost analysis assumes current technology costs, and makes no assumptions about the cost trajectory (up or down) of particular technologies over time due to potential transformation of the market.
- Average electricity costs per kilowatt hour are expressed as statewide averages and are not indicative of individual utilities' rates or the actual bills that consumers will pay.

Three Illustrative Timelines Created for Analysis

This report then uses the 33% RPS Reference Case to construct three illustrative timelines for achieving a 33% RPS. These timelines demonstrate how and when the state could plausibly build the necessary renewable generation and transmission to reach a 33% RPS. The timelines also offer insights into the increased need for public and private sector resources in order to quickly process the increased number of transmission and generation applications over the next 10 years.

- **Illustrative Timeline 1: Historical experience without process reform**

  This scenario is based on the state's experience with generation and transmission development over the last 10-15 years. The timeline assumes transmission planning, permitting, and construction processes that are almost entirely sequential.

- **Illustrative Timeline 2A: Current practice with process reform and no external risks**

  This scenario represents the development trajectory if California successfully implements transmission and generation process reforms that are already underway. Although not plausible since it does not include external risks that are beyond the state's control, this timeline serves to isolate the effect of the process reforms, and is the reference point that Timeline 2B is built upon.

- **Illustrative Timeline 2B: Current practice with process reform and external risks**

  This scenario represents the development trajectory if California successfully implements process reforms, but includes negative impacts and delays from external risks outside the direct control of state agencies, such as emerging technology risk, financing difficulties, and public opposition or legal challenges.

FINDINGS

Key Findings from Timeline Analysis:

The report finds that a 33% RPS in 2020 is highly ambitious, given the magnitude of the infrastructure buildout required

The magnitude of the infrastructure that California will have to plan, permit, procure, develop, and integrate in the next ten years is immense and unprecedented. This goal is more attainable with a commitment of significant new staff resources in both the public and private sectors. The conclusions below are based on an implementation analysis of the 33% RPS Reference Case.

- Timeline 1 reaches a 33% RPS in 2024. Using past practices as a guide, the scale of the transmission and generation buildout will take at least 14 years if implementation starts today. This timeline, however, assumes no external risks.
- Timeline 2A reaches a 33% RPS in 2021. This timeline assumes successful implementation of numerous process reforms now underway, which speed achievement of the 33% RPS from 2024 to 2021. This timeline represents a best case scenario as it assumes no external risks, no resource constraints in processing numerous transmission and generation applications, and that the California ISO is able to successfully implement its planned new process to review and approve more than one major transmission application per year.
- Timeline 2B does not reach the 33% RPS since two resource zones fail to develop due to risks outside of the state's control.

Numerous external risks could undermine the time savings achieved by process reforms

Several factors outside direct state control could undermine the gains realized through the various reform initiatives. These external risks could delay attainment of the 33% RPS target well beyond 2020, especially if California continues on its current renewable resource contracting path.

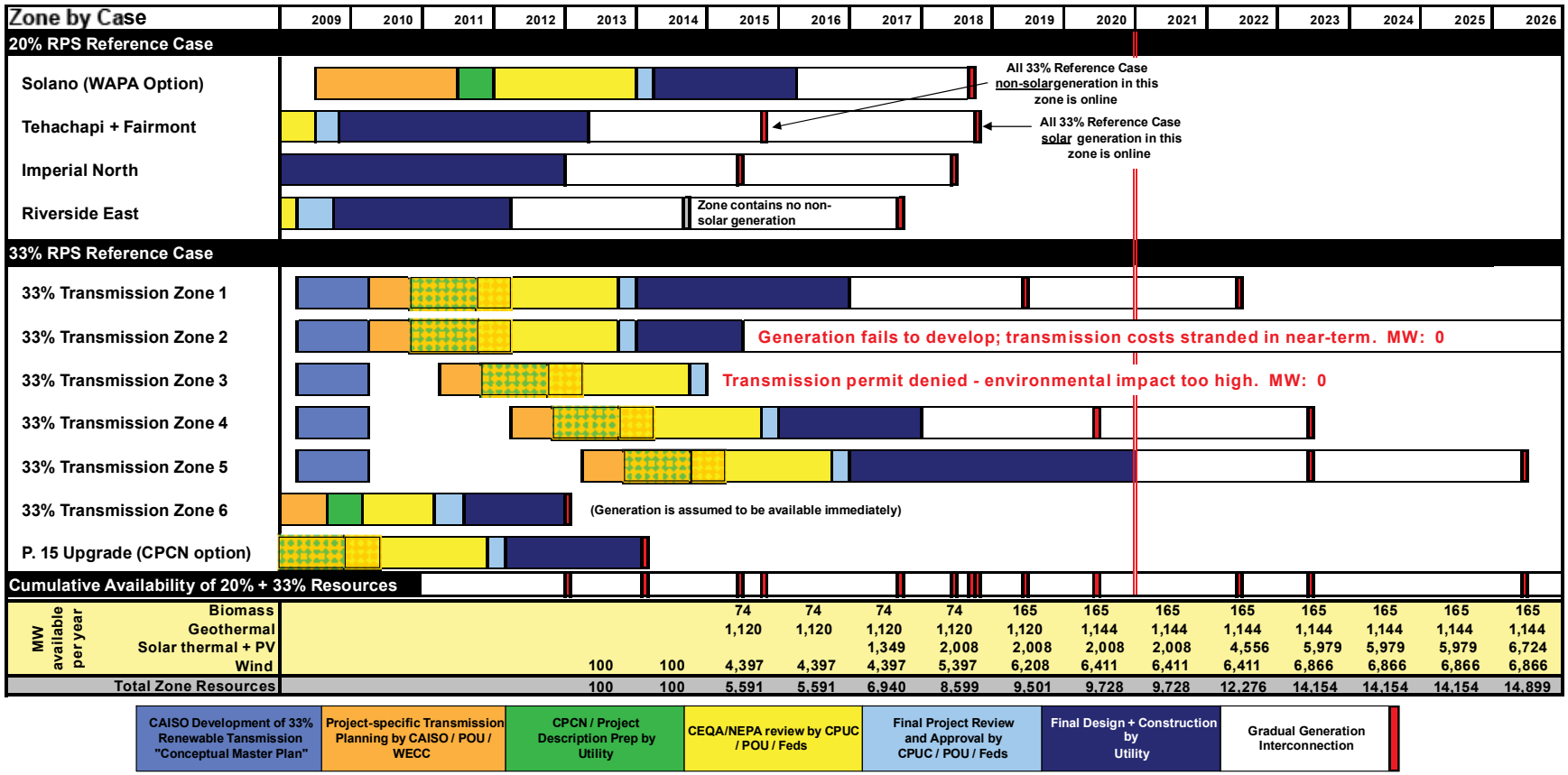
- Timeline 2B (see Exhibit A) illustrates how unanticipated contingencies could affect the timing of reaching the 33% RPS goal. External risks delaying this timeline include:
    - California's high reliance on relatively new technologies and companies
    - Scale of new infrastructure investment, which this analysis estimates at approximately $115 billion between now and 2020, in an uncertain financial environment
    - Environmental impacts of generation and transmission facilities that may require the use of large areas of undeveloped and perhaps pristine land
    - Legal challenges and public opposition to large-scale renewable energy infrastructure

California must start implementing mitigation strategies if achieving a 33% RPS by the year 2020 is the most important policy priority

Timeline 2B provides an example of a scenario in which, despite successful implementation of ambitious reforms, two resource zones fail to develop due to external risks. While Timeline 2B presents a hypothetical example, it illustrates the potential impact of real risks that California's current procurement strategy is not prepared to mitigate. Specifically, California's current procurement path is focused almost solely on central station renewable generation that is dependent on new transmission. In order to mitigate the risk that one resource zone would fail to develop, thereby delaying the achievement of a 33% RPS by several years, the state should consider a procurement strategy that adequately considers the time and risk, in addition to price, associated with particular renewable generation resources. The state may also wish to adopt risk mitigation strategies, such as:

- Planning for more transmission and generation than needed to reach just 33%
- Pursuing procurement, such as distributed solar photovoltaics (PV), which is not dependent on new transmission
- Concentrating renewable development in pre-permitted land that would be set aside for a renewable energy park

Exhibit A. Illustrative Timeline 2B for the 33% RPS Reference Case: Current Practice With Process Reform and External Risks



Source: CPUC/Aspen

Result: The 33% RPS Reference Case is not achieved due to unexpected problems with the development of two zones and delays in deployment of large-scale solar projects. Regardless of the nature of the risks that may actually occur, realization of any risk could cause delay and have a significant impact on timing. Although the state does not have direct control over many of the risks facing renewable energy development, it could adopt strategies that would mitigate specific risks.

Key Findings from Renewable Resource and Cost Analysis

A 33% RPS is projected to require almost a tripling of renewable electricity, and nearly a doubling of new transmission lines

The 33% RPS Reference Case is projected to require an additional 75 TWh of renewable electricity, or nearly a tripling compared to the 27 TWh of delivered renewable electricity generated at the end of 2007. It is also projected to require seven new transmission lines to deliver the additional 75 TWh of electricity.

Exhibit B. Renewable Generation and Transmission Needed in 2020

20% RPS Reference Case would require	33% RPS Reference Case would require
35 TWh of new renewable electricity in 2020, in addition to **27 TWh** of generation from renewables in existence at the end of 2007	**75 TWh** of new renewable electricity in 2020, in addition to **27 TWh** of generation from renewables in existence at the end of 2007
4 New Major Transmission Lines at cost of **$4 Billion**	**7** Additional Major Transmission Lines at cost of **$12 Billion**

Electricity will be higher in 2020 regardless of the RPS requirements

Real electricity costs will be significantly higher in 2020 compared to 2008, regardless of whether California pursues a 20% or 33% RPS (see Exhibit B).

- Even if California makes no further investments in renewable energy (the all-gas scenario), the analysis projects that average statewide electricity costs per kilowatt hour will rise by 16.7% in 2020 compared to 2008 in real terms. This increase results from the need to maintain and replace aging transmission and distribution infrastructure, anticipated investments in advanced metering infrastructure and other smart grid capabilities, the cost of repowering or replacing generators to comply with once-through cooling regulations, and the cost of procuring new conventional generating resources to meet load growth.
- In 2020, the total statewide electricity expenditures of the 20% RPS Reference Case is projected to be 2.8% higher compared to the all-gas scenario.
- In 2020, the total statewide electricity expenditures of the 33% RPS Reference Case is projected to be 7.1% higher compared to the 20% Reference Case, and 10.2% higher compared to the all-gas scenario.

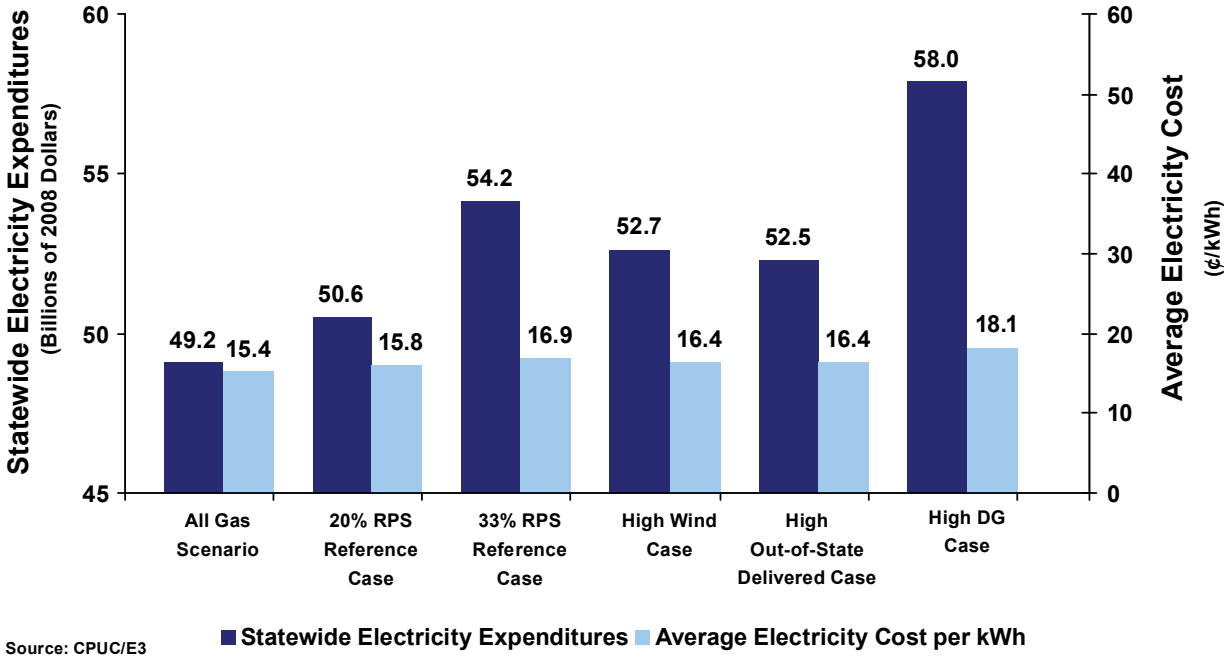
The 33% RPS Reference Case is the most expensive case relative to the alternative 33% RPS cases requiring new transmission lines; but it is still much less costly than the High DG Case (see Exhibit B)

The cost premium of meeting a 33% RPS does not vary greatly between the High Out-of-State Delivered Case and the High-Wind Case. Statewide electricity expenditures under these cases are $1.5 and $1.8 billion lower than the 33% RPS Reference Case, respectively, with the cost savings largely resulting from replacing large quantities of solar thermal resources with less costly wind resources.

The High DG Case adds almost twice the incremental costs of the 33% RPS Reference Case

The cost premium of the High DG Case is significantly higher than the 33% RPS alternative cases, with a 14.6% cost premium compared to the 20% RPS Reference Case, and a 7.0% cost premium compared to the 33% RPS Reference Case. This is due to the heavy reliance on solar PV resources, which are currently more expensive than wind and central station solar.

Exhibit C. Statewide Electricity Expenditures and Average Electricity Cost in 2020



Source: CPUC/E3

Findings from Sensitivity Analysis

Projecting the costs of different renewable and fossil-fired energy sources out to 2020 requires numerous assumptions about future conditions including load growth, equipment costs, and fuel prices. Many of these variables are highly uncertain, and some significantly influence the model's results. Accordingly, the study includes sensitivity analysis in three key areas, finding that:

- A 33% RPS can serve as a hedge against natural gas prices, but only under very high natural gas and GHG allowance prices. Thus, the hedging value in itself is not a very strong justification to do a 33% RPS.
- The interplay between energy efficiency achievement and renewable energy procurement highlights the need to analyze and plan for the interactions among the state's various policy goals. If the state does not plan for interactions, then a 33% RPS by 2020 could result in a surplus of energy or capacity and excess consumer costs.
- Dramatic cost reductions in solar PV could make a solar DG strategy cost-competitive with central station renewable generation. More analysis is necessary to determine the programmatic strategies necessary to achieve a high-DG scenario as well as the feasibility of high penetrations of solar PV on the distribution grid.

POLICY OBJECTIVES AND TRADEOFFS

Achieving a 33% RPS will require tradeoffs amongst various policy goals and objectives

There are multiple renewable procurement strategies that California could pursue to reach a 33% RPS, but each procurement path will reach the 33% RPS target on a different timeframe and will perform differently across the broad range of RPS policy objectives that stakeholders and decision-makers have articulated. See Exhibit D for a comparison of how each 33% RPS Case performs across the RPS policy objectives.

Exhibit D. Comparison of 33% RPS Cases Across RPS Policy Objectives

Policy Objective	33% RPS Reference Case	High Wind Case	High Out-of-State Delivered Case	High-DG Case
Cost	◒	●	●	○
Timing	○	◒	◒	◒
GHG Emission Reductions	●	●	●	●
Resource Diversity (Hedging Value)	●	●	●	●
Local Environmental Quality Air Quality	●	◒	○	●
Local Environmental Quality Land Use	○	◒	◒	●
In-state Economic Development	◒	◒	○	◒
Long-Term Transformation	●	○	○	●
Technology Development Risk	○	●	●	○

Legend:

● Case performs well ○ Case performs poorly ◒ Case is neutral

California IOUs are currently on a procurement path that in effect prioritizes long-term market transformation over other policy objectives. California's IOUs are depending on new renewable technologies, including solar thermal, to meet their RPS obligations. This procurement strategy may lead to long-term market transformation of the central station solar market, but due to risks inherent to new technologies, this strategy could result in higher prices and a longer development period that could delay achievement of a 33% RPS to after 2020.

RPS Policy Objectives Should Be Prioritized

As this analysis has shown, many of the policy objectives are mutually exclusive and in conflict with one another. Currently, the RPS procurement process is in effect dictating the timing, cost, and policy objectives of a future 33% RPS program. Thus, the tradeoffs are being decided through the utility procurement process, not by the policymakers or regulators. Using current RPS contracts as an example, market transformation and in-state economic development are the primary policy objectives that are being prioritized at the expense of meeting a 2020 timeline and minimizing customer costs. This results from lack of having a stated priority preference. Some of the key questions to help determine a priority preference include:

- Should California focus public investment and system planning efforts on developing and integrating technologies with significant long-term transformational potential such as solar thermal or solar PV?
- Should California focus on developing in-state resources? Up to what cost? What is the correct balance between in-state economic development and higher customer costs?
- Is California willing to delay the 2020 target in order to develop primarily California resources and stimulate new technologies and market transformation?
- Should California waive renewable energy delivery requirements for out-of-state resources if it is necessary to meet the 2020 target or pursue a lower cost strategy?
- Should the CPUC encourage the utilities to procure increased amounts of (currently) high-cost solar PV to mitigate the potential negative impact of delay due to failure of a resource zone?

NEXT STEPS

This report presents the preliminary results of the 33% RPS Implementation Analysis and does not include results from Phase 3, the final phase of this analysis. By the end of 2009, the final results will incorporate additional analyses. First, the California ISO will complete a study to determine the resource requirements to integrate the intermittent renewable resources needed for a 33% RPS. Second, the transmission cost estimates will be updated based on the latest information from the Renewable Energy Transmission Initiative (RETI) and the California ISO's conceptual transmission planning process. Finally, CPUC staff will identify and articulate solutions and strategies for addressing many of the risks and challenges identified throughout this report.

2 Introduction

The CPUC, in conjunction with the Energy Commission, is responsible for implementing the state's Renewables Portfolio Standard Program, which is one of the most ambitious renewable energy standards in the country. California lawmakers are contemplating increasing the current RPS mandate, which is 20% renewable energy by 2010, to 33% renewable energy by 2020. A 33% renewable goal could further California's efforts to address climate change and lead the nation in proactive clean energy policy. The CPUC supports this more aggressive 33% renewable energy standard and recommended it as a key electric sector strategy in the Energy Commission/CPUC joint recommendations to the California Air Resources Board to help California meet its climate change targets established in AB 32, the Global Warming Solutions Act of 2006. The ARB adopted this recommendation in December 2008. [1]

The CPUC's Energy Division staff initiated this study in August 2008 in order to provide a quantitative analysis of the costs and risks of alternative means of achieving a 33% RPS by 2020.[2] The report seeks to answer two key questions: 1) How much will it cost to meet a 33% RPS, and 2) how will the state reach a 33% RPS by 2020? Working with a broad stakeholder group, including the investor-owned electrical utilities, industry experts, ratepayer advocates, and environmental groups, the study team, which consisted of CPUC staff and a consulting team, developed the preliminary results presented in this report. The report analyzes four different possible 33% RPS alternatives and articulates the costs and tradeoffs of each approach. The study team used the 33% RPS Reference Case to construct three illustrative timelines for achieving a 33% RPS. These timelines demonstrate how and when the state could plausibly build the necessary renewable generation and transmission to reach a 33% RPS. CPUC staff will issue a final report by the end of 2009, which will be informed by additional analysis that the California ISO is conducting.

POLICY GOALS AND OBJECTIVES

California has been leading the country with aggressive renewable energy targets since the establishment of the RPS in 2002. Senate Bill (SB) 1078 established Public Utilities Code Section 399.11 - 399.15, which created California's first RPS law and mandated a 20% RPS by 2017.[3] Just three years later, in 2005, the legislature amended the statute to accelerate this goal to 20% by 2010.[4] Current statute expressly prohibits the CPUC from requiring an RPS level beyond the 20% target.

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[1] California Air Resources Board, "Climate Change Scoping Plan," Approved December 11, 2008. Available at: http://www.arb.ca.gov/cc/scopingplan/document/scopingplandocument.htm.

[2] CPUC Decision (D.)07-12-052, which authorized the 2007 long-term procurement plans (LTPPs), directed Energy Division staff to work with stakeholders to refine a methodology for evaluating a 33% RPS by 2020 within the context of LTPP.

[3] Senate Bill 1078 (2002), Section 3, Article 16, PU Code Section 399.11(a)(b)(c)

[4] Senate Bill 107 (2006)

In November 2008, Governor Schwarzenegger issued Executive Order S-14-08, requiring state agencies to establish the Renewable Energy Action Team to streamline the review of transmission and renewable generation projects as well as commit state agencies to work towards achieving 33% of retail sales from renewable energy by 2020.[5] The legislature is currently considering several different bills that would mandate a 33% RPS by 2020.

Through legislation and other measures, state policymakers have articulated various policy goals and objectives that a 33% RPS should address:

- **Greenhouse Gas Emission Reductions**. California can avoid significant GHG emissions by replacing one-third of the state's energy supply with renewable resources. As part of its strategy to reduce emissions to 1990 levels by 2020, ARB has estimated that a 33% RPS could reduce GHG emissions by 21.3 million metric tons of carbon dioxide equivalent ($MMTCO_2e$), satisfying nearly 12% of the total required GHG reductions.
- **Long-Term Market Transformation.** An aggressive RPS target should help to drive the energy technology transformations needed to lower costs, upgrade current infrastructure, and achieve long-term GHG reductions beyond 2020. Scientists estimate that deep cuts in global GHG emissions of 50% to 85% below current levels by 2050 are necessary to prevent the worst impacts from climate change.[6]
- **Resource Diversity.** Higher levels of renewable energy generation can improve the diversity and security of California's energy supply, provide hedging value, and reduce dependence on fossil fuels with volatile prices, particularly natural gas.
- **Local Environmental Quality and Public Health.** Renewable generation can improve local air quality and public health, principally through reduced emissions of criteria pollutants at gas-fired power plants in California.
- **Economic Development.** Renewable technologies can create local manufacturing, installation, maintenance, and operational jobs.
- **Least-Cost, Best Fit.** Public Utilities Code Section 399.14 requires a renewable project selection process called "least-cost, best-fit," which allows the utility to select the project based on the value to the ratepayer and the utility. The statute requires the CPUC to consider estimates of indirect costs associated with the project, including new transmission investments and ongoing utility expenses resulting from integrating and operating renewable energy resources. Consequently, this report describes both the cost and "fit" attributes of four different portfolios of renewable resources.
- **Timing**. Since the ARB has linked a 33% RPS to the 2020 climate change goals, the speed at which renewable resources can be developed and integrated into the power grid is very important.

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[5] California Governor's Executive Order S-14-08, "Governor Schwarzenegger Advances State's Renewable Energy Development," November 17, 2008. Available at: http://gov.ca.gov/press-release/11073/.

[6] Intergovernmental Panel on Climate Change, "Climate Change 2007: Synthesis Report," 2007, Section 5.4, pg. 66-67, Assessment of the Intergovernmental Panel on Climate Change, Valencia, Spain. California Governor Schwarzenegger committed California to reduce statewide GHG emissions to 80% below 1990 levels by 2050 in Executive Order S-3-05, June 1, 2005. Available at: http://gov.ca.gov/executive-order/1861/.

STUDY OVERVIEW

Several other studies and processes have examined, or are now examining, a particular aspect of a California 33% RPS. Some of these studies have occurred in the past, while others are occurring in parallel with this analysis. These studies include:

- Center for Resource Solutions report prepared for the CPUC (2005)[7]
- E3's modeling work to develop the GHG Calculator in support of the joint CPUC/Energy Commission proceeding to develop recommendations for the ARB on implementation of AB 32 for the electricity sector[8]
- California ISO Preliminary Report on Renewable Transmission Plans (2008)[9]
- California ISO's Integration of Renewable Resources Program[10] to evaluate the generation performance characteristics and gas-fired generation needed to support increased levels of various types of renewable resources
- Energy Commission 2009 Integrated Energy Policy Report (IEPR) proceeding
- Ongoing work of RETI and other transmission planning processes to facilitate the interconnection of renewable generators

This study provides a more in-depth, granular, and comprehensive analysis of different possible renewable scenarios compared to these previous studies. It draws heavily on most of the sources described above for data and assumptions, including RETI and the GHG Calculator, both of which were scrutinized and evaluated through stakeholder processes. The analysis also used a stakeholder working group to vet and refine the study methodology, assumptions, and inputs, especially when the assumptions differed from existing studies. For example, the renewable technology cost numbers from RETI were used, except the financing assumptions were modified to incorporate recent changes in financial markets. This report also incorporates new resource potential identified in RETI and other sources, existing resources from the Western Electricity Coordinating Council's (WECC) most recent west-wide study cases,[11] and proposed projects under development (identified through utility procurement solicitations). As a result, the renewable energy project and cost data underlying this analysis is the best publicly available data to date.

In addition, this study is the first effort to create comprehensive generation and transmission timelines that illustrate the many steps required to bring renewable energy projects in California from conception to commercial operation. This study elevates the analysis from a general discussion of perceived barriers into illustrative timelines that depict the magnitude of the coordination challenge associated with a 33% RPS.

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[7] http://www.resource-solutions.org/lib/librarypdfs/Achieving_33_Percent_RPS_Report.pdf
[8] http://www.ethree.com/CPUC_GHG_Model.html
[9] http://www.caiso.com/2007/2007d75567610.pdf
[10] See http://www.caiso.com/1c51/1c51c7946a480.html for status and documents related to this program.
[11] The analysis is built off of the November 2008 version of the WECC's Transmission Expansion Planning and Policy Committee (TEPPC) 2017 database.

Assumptions

Like any modeling effort, this study makes a number of simplifications in order to represent a complex problem in manageable proportions. Likewise, the analysis includes assumptions about the future that are not known today. First, this study is a statewide analysis, and not limited to the investor-owned utilities (IOUs). Second, this analysis used high-level estimates of renewable integration and transmission costs, which will be updated in the next phase of this study. Third, the technology costs presented in this analysis reflect the costs to build and operate the renewable project with a reasonable profit, but are not based on actual contract prices. Many of the other assumptions are stated below or are explained in the relevant sections throughout the report and in the methodology discussion found in Appendix B.

Study Outputs

This report presents the preliminary results of the first two phases of this three-phase study. The key outputs are described below.

Four Unique 33% RPS Cases

The study team developed four unique 33% RPS cases, or renewable resource portfolios, for achieving a 33% RPS by 2020. Each case addresses a different possible scenario. For example, the 33% RPS Reference Case reflects California's current renewable procurement path, which is focused partly on new technologies, such as central station solar. Three alternative 33% RPS cases were developed, which test the costs and benefits of a particular resource strategy, including higher levels of wind energy, out-of-state resources, and distributed renewable resources.

Renewable Resource Portfolio

A resource portfolio is a collection of renewable resources by quantity and technology type selected based on different constraints or policy objectives.

A fifth case was developed, termed the 20% RPS Reference Case, to serve as a point of comparison for any cost changes associated with a 33% RPS. The 20% RPS Reference Case reflects current state law and utility procurement. Two additional scenarios were developed to provide further points of reference: an all-gas scenario, which represents the resource mix in 2020 if no additional renewables were developed beyond 2007, and the rest of California's electricity needs were met with gas-fired generation, and 2008 Costs, which represents the current cost of electricity in California.

Estimates of Renewable Generation and Transmission

This report presents plausible estimates of the type and amount of renewable generation and transmission needed to reach a 33% RPS. The Energy Commission's 2007 IEPR load forecast was used to project electricity sales to 2020. The study team calculated the quantity of new renewable resources needed to meet the 33% RPS and then selected renewable resources to fill this need. The study also provides a high-level estimate of the new transmission investment needed to integrate and deliver renewable resources to load centers. However, the study did not undertake a detailed engineering analysis of the ability of the renewable resources to connect to the existing grid. It also does not reflect the conceptual transmission plans that RETI is currently developing, since these were not available at the time of this analysis. As a result, the

transmission investment assumed in the cases does not represent an "optimal" or least-cost transmission plan. The study team will update the transmission results in the final phase of this study based on the transmission conceptual plans that RETI and the California ISO are developing.

Electricity Costs in 2020

All electricity costs are presented in 2008 dollars unless noted otherwise. This analysis calculated statewide electricity expenditures, which is an economic cost, for the different RPS cases in the year 2020, as well as the average cost per kWh in 2020. All costs include federal production and investment tax credits and state property tax incentives. This analysis did not calculate ratepayer bill impacts, which depend on policy design, cost allocation, and how economic costs are recovered through different rate classes. In addition, this analysis employed simplified assumptions for transmission costs and integration costs in lieu of detailed California ISO analysis. These cost assumptions will be updated in the final report following further analysis.

To estimate the cost of constructing new renewable resources, the study team relied primarily on data developed for the state's RETI process. RETI developed cost and performance information for hundreds of potential projects throughout California, representing tens of thousands of megawatts of renewable energy resources. Additional resource characterizations came from the GHG Calculator.

For most of the projects, the costs are the developer costs to build and operate the project with a reasonable profit. The project costs are not the negotiated contract prices. However, projects that were projected to cost less than a combined cycle gas turbine (CCGT) power plant were assumed to be at least as expensive as a CCGT, even if some renewable resources may be slightly less expensive to develop. E3 made the assumption that the CCGT cost serves as a floor for the cost of a renewable power purchase agreement (PPA) since until low-cost renewables are widely available, it is unlikely that developers will agree to supply power to California utilities below the market rate for new conventional resources. This assumption has a modest, upward impact on the total cost of complying with a 33% RPS.

Illustrative Timelines for Generation and Transmission Facilities

As mentioned above, this analysis created illustrative timelines for the generation and transmission facilities needed to meet a 33% RPS. These timelines show the time needed to reach a 33% RPS under three scenarios: a) historical experience without process reform, b) current practice including process reform and no external risks, and c) current practice with process reform and external risks. The study team constructed timelines only for the 33% RPS Reference Case and did not perform this analysis on the other three alternative 33% RPS cases.

This analysis also identified several external risks that are outside of the state's control. These risks include technology risk, financing risk, environmental impacts, and potential legal challenges and public opposition to transmission and generation permits. The report shows how these risks could cause delay despite the progress the state is making in streamlining current renewable generation and transmission permitting processes.

3 33% RPS Resource Portfolio Results

This section describes the renewable resource mixes developed for each 33% RPS case and presents the impact of these resource mixes on total statewide electricity expenditures, average statewide electricity costs, and GHG emissions relative to an all-gas scenario and the 20% RPS Reference Case. A brief overview of the methodology is provided below, with a more complete description in Appendix B.

In order to conduct the analysis, E3 first created an RPS Calculator, which is a Microsoft Excel spreadsheet model developed to aggregate the renewable cost and performance data and select renewable resources needed to meet the RPS target. The model identifies transmission investments that deliver renewable resources to load and conventional resources that are needed to meet energy and peak demand growth. It also calculates the cost and GHG impacts of a given portfolio of resources in 2020. Second, E3 calculated the renewable resource need to determine how much renewable energy the state needs to procure between now and 2020 to meet the 33% RPS. E3 used the Energy Commission's 2007 IEPR load forecast to project statewide electricity load in 2020, which included assumptions on the state's achievement of energy efficiency, demand response, combined heat and power, and the California Solar Initiative.[12] In order to fill this need, data was collected drawing from the sources described in Table 1. Next, each renewable project was placed into a resource zone, which is an aggregation of renewable resources in a contained geographic area. These zones were then ranked by both economic and environmental factors. From this data, the study team developed five different renewable energy cases, which are described in Table 2.

[12] California Energy Commission, "California Energy Demand 2008 – 2018 Staff Revised Forecast," CEC-200-2007-015-SF2, November 2007: http://www.energy.ca.gov/2007publications/CEC-200-2007-015/CEC-200-2007-015-SF2.PDF

Table 1. Data Sources Used in 33% RPS Implementation Analysis

Data Source	Description
CPUC Energy Division project database (ED Database)	The Energy Division maintains a database of renewable energy projects representing approximately 56 TWh of electricity that the IOUs have selected through RPS solicitations.[13] The projects are in various stages of completion, ranging from projects under negotiation (i.e., short-listed for negotiating a contract by an IOU), to projects that are online. Incorporating short-listed projects distinguishes this study from prior analyses by enabling it to take advantage of information about commercial interest in specific new renewable projects.
Renewable Energy Transmission Initiative	The RETI process developed a detailed and comprehensive database of renewable resource potential in California and neighboring states.[14] The RETI analysis provided a stakeholder-vetted engineering assessment of renewable resources at the project level by location and technology type. The RETI dataset relies on proxy projects that are based on expressed commercial interest, it does not include short-listed projects. In addition to renewable resource information, the RETI database categorized clusters of renewable development into renewable resource zones, which were extremely valuable in the estimates of resource development and transmission need.
The GHG Calculator	E3 developed a database of renewable resource potential throughout the WECC as part of its GHG modeling analysis for the CPUC, ARB, and the Energy Commission. The study team relied on the E3 database for information on renewable resources outside of California.[15]
Estimates of distributed renewable energy potential	E3 developed new estimates of the technical potential to connect distributed renewable generation in California. While the distributed solar photovoltaic technical potential estimates that were developed for this study are very high-level, they are useful for the purpose of testing the benefits and costs of distributed renewables relative to central station power plants to achieve a 33% RPS.

[13] The CPUC maintains a public version of this database: www.cpuc.ca.gov/renewables
[14] Renewable Energy Transmission Initiative: www.energy.ca.gov/reti/documents/index.html
[15] The E3 database compiled the data through GIS date from the National Renewable Energy Laboratory, the Energy Information Administration, the Energy Commission, and the Western Governor's Association. More detailed information is available here: http://ethree.com/CPUC_GHG_Model.html.

Table 2. 2020 Cases Developed for the 33% RPS Implementation Analysis

Case Name	Description
20% RPS Reference Case	Utilities procure 35 TWh of additional renewables to meet a 20% RPS target by 2020.
33% RPS Reference Case	Utilities procure 75 TWh of additional renewables to meet a 33% RPS target by 2020. There is heavy emphasis on projects that are already either contracted or short-listed with California IOUs, which includes a significant proportion of solar thermal and solar photovoltaic resources.
High Wind Case	Assumes less reliance on in-state solar thermal and more reliance on the less expensive wind resources in California and Baja.
High Out-of-State Delivered Case	Allows construction of new, long-line, multi-state transmission to allow California utilities to procure large quantities of low-cost wind and geothermal resources in other western states. Does not use tradable renewable energy certificates as a compliance tool. Thus, all out-of-state electricity is delivered to California.
High DG Case	Assumes limited new transmission corridors are developed to access additional renewable resources to achieve a 33% RPS. Instead, extensive, smaller-scale renewable generation is located on the distribution system and close to substations.

RENEWABLE RESOURCES NEEDED

Table 3 shows the calculation of the quantity of renewable resources that California utilities must procure between 2008 and 2020 to meet a specified RPS target – for both a 20% and a 33% RPS.

Table 3. New Renewable Resources Required to Meet a 33% RPS by 2020 in TWh

	20% RPS	33% RPS
2020 retail sales forecast [16]	308	308
Required RPS resources	62	102
RPS resources claimed by utilities in 2007[17]	27	27
Resources needed to reach RPS	*35*	*75*

RESULTING RPS RESOURCE MIXES

Figure 1 provides the renewable energy resource mixes for each RPS case, which were derived using the RPS Calculator. The renewable energy resource mixes for each case vary significantly across portfolios. The 33% RPS Reference Case has the most large-scale solar compared to all of the other cases. The High Out-of-State Delivered Case contains the largest proportion of out-of-state resources, such as geothermal energy, and nearly as much wind as the High Wind Case.

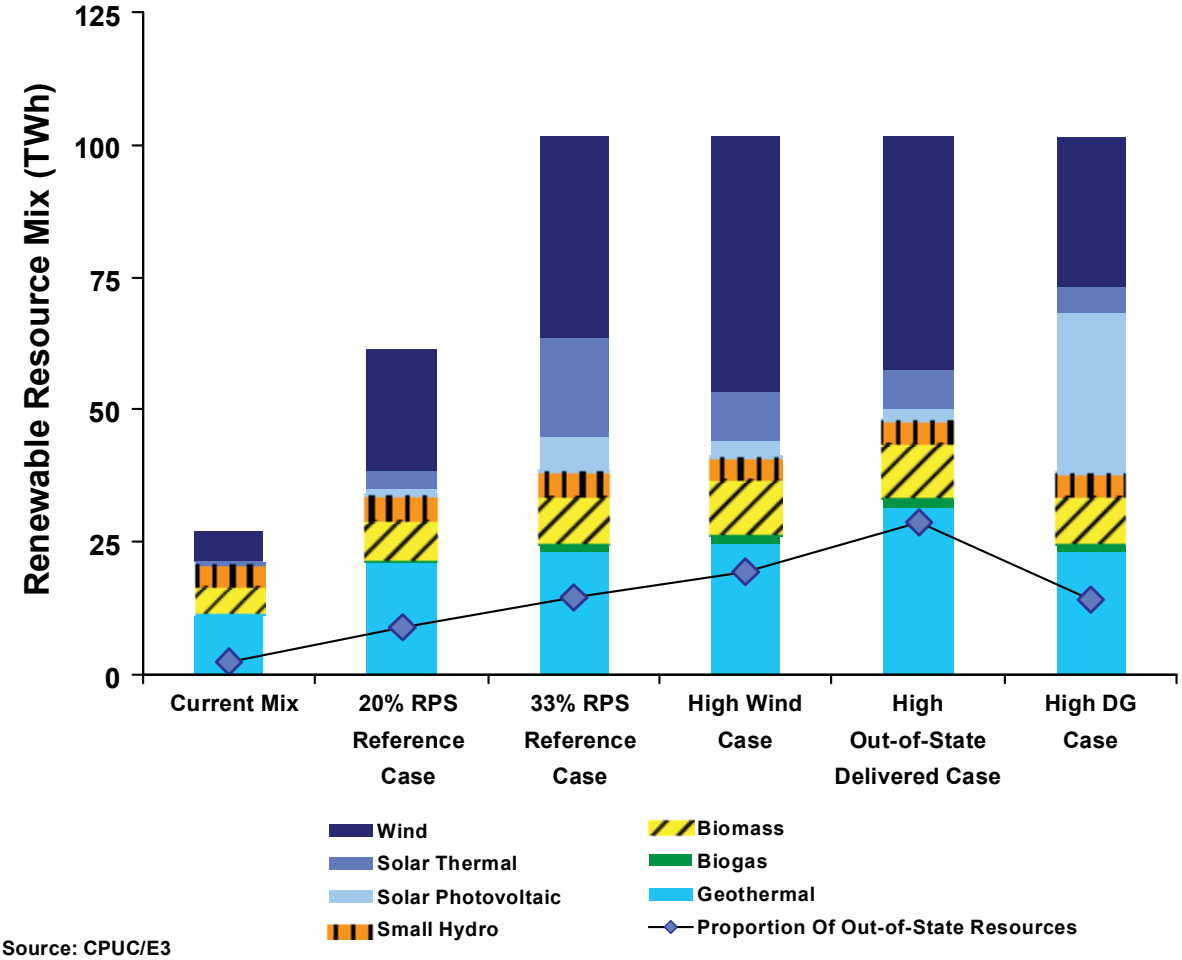
[16] Source: California Energy Commission, 2007, "California Energy Demand 2008 - 2018 Staff Revised Forecast," Energy Commission-200-2007-015-SF2, (excludes sales by California water agencies) extrapolated from 2018 to 2020 based on historic growth trends

[17] Source: Energy Commission 2007 Net System Power Report

The bioenergy and small hydro proportions do not vary greatly across the cases. The High DG Case includes a much larger proportion of solar PV than any other case.

Figure 1 also shows the level of renewable energy from the various resources in each case, inside and outside of California. All cases assume existing statutorily-required out-of-state energy delivery requirements.[18] The High Out-of-State Delivered Case and the High Wind Case have a higher proportion of renewable energy developed outside of California compared to the other cases. Thus, this study does not examine the potential for or costs and benefits of the use of tradable RECs with no delivery requirement as a compliance mechanism in the RPS program.

Figure 1. Renewable Resource Mixes in 2020 under Different Cases



Source: CPUC/E3

[18] California Public Resources Code Section 25741(a) states that facilities located in California or with their first point of interconnection in the state are automatically deemed "delivered," eligible renewable energy from out-of-state facilities must be "scheduled for consumption by California end-use retail customers" to be counted for compliance with the RPS program. The RPS statute also allows "electricity generated by an eligible renewable energy resource [to] be considered 'delivered' regardless of whether the electricity is generated at a different time from consumption by a California end-use customer. The Energy Commission's RPS Eligibility Guidebook interprets this to mean that out-of-state energy may be "firmed" and "shaped," or backed up or supplemented with delivery from another source, before it is delivered to California.

Table 4 shows the locations of the renewable resources in the 33% RPS Reference Case. The resources fall into two categories: those that need additional transmission development, and those that do not. Resources that do not need new in-state transmission were aggregated into relatively homogenous clusters. Similar tables for the three alternative 33% RPS cases are included in Appendix C.

Table 4. Locations of Renewable Resource Zones in 33% RPS Reference Case

Resource Zones Selected in Reference Cases		
Included in 20% and 33% RPS Reference Cases		
	MW	**GWh**
Tehachapi	3,000	8,862
Distributed CPUC Database*	525	3,118
Solano	1,000	3,197
Out-of-State Early*	2,062	6,617
Imperial North	1,500	9,634
Riverside East	1,350	3,153
Included in 33% RPS Reference Case Only		
Mountain Pass	1,650	4,041
Carrizo North	1,500	3,306
Out-of-State Late*	1,934	5,295
Needles	1,200	3,078
Kramer	1,650	4,226
Distributed Biogas*	249	1,855
Distributed Geothermal*	175	1,344
Fairmont	1,650	5,003
San Bernardino - Lucerne	1,800	5,020
Palm Springs	806	2,711
Baja	97	321
Riverside East Incremental	1,650	3,869
Total	**23,798**	**74,650**

* Aggregations of renewable resources that do not need new in-state transmission development.

RPS COSTS IMPACTS AND GHG EMISSION REDUCTIONS

This section describes the cost impacts for each RPS case. Specifically, the 33% RPS cases are compared to the 20% RPS Reference Case. These costs, however, are uncertain for a number of reasons. Chief among these are: a) Use of planning-level data regarding technology cost and performance from RETI and other sources rather than contract prices associated with any particular project; b) Assumption of no changes in renewable technology costs or performance over time; c) Use of high-level estimates of transmission and renewable integration costs; d) Natural gas prices are highly volatile and may be very different from forecasted values; e) Use of a number of assumptions about GHG regulation including the cost of carbon dioxide (CO_2) allowances in 2020 and the allocation of allowance auction revenues to electric utility ratepayers. While new data that is forthcoming from RETI and the California ISO may help to refine cost

estimates, uncertainty is inherent in any long-term planning exercise, which should be kept in mind when interpreting these results.

All-Gas Scenario and 20% RPS Reference Case

Average California electricity costs per kilowatt-hour are expected to increase substantially between now and 2020 even without new investments in renewable resources. Table 5 shows California's projected statewide electricity expenditures in 2008 and in 2020 for an all-gas scenario in which no new renewable projects are built after 2007. This all-gas scenario is designed to show the overall change in the California electricity system by 2020 if no additional renewable resources are built after 2007. Average electricity costs per kilowatt-hour are expected to increase by 16.7% from 2008 to 2020 under the all-gas scenario. This increase results from the need to maintain and replace aging transmission and distribution infrastructure, anticipated investments in advanced metering infrastructure and other smart grid capabilities, the cost of re-powering or replacing generators to comply with once-through cooling regulations, and the cost of procuring new conventional generating resources to meet load growth. Under the 20% RPS Reference Case (current law), the average electricity costs per kilowatt-hour increase would be 19.7% compared to 2008.

Table 5. Projected California Electricity Costs in 2020 (billions of 2008 dollars)

Category	2008	All-Gas Scenario in 2020	20% RPS Reference Case in 2020	33% RPS Reference Case in 2020
Existing and New Conventional Generation Fixed Costs	$8.5	$11.8	$11.1	$9.9
Existing and New Conventional Generation Variable Costs	$13.2	$16.5	$14.2	$11.6
Existing Transmission and Distribution	$15.1	$20.5	$20.5	$20.5
New Transmission for Renewables	N/A	N/A	$0.5	$1.8
New Renewable Generation and Integration	N/A	N/A	$4.3	$10.8
CO_2 Allowances[19]	N/A	$0.4	- $0.03	- $0.5
Total Statewide Electricity Expenditures	**$36.8**	**$49.2**	**$50.6**	**$54.2**
Average Statewide Electricity Cost per kWh	**$0.132/kWh**	**$0.154/kWh**	**$0.158/kWh**	**$0.169/kWh**

[19] Assumes that revenues from the auction of 108 MMT of CO_2 allowances (based on estimate 2008 electric sector emissions) are used to reduce utility rates. Does not include additional CO_2 costs that are reflected in higher market prices.

Implication: Electricity costs will increase significantly in 2020 compared to 2008, regardless of whether California mandates a 33% RPS or not.

33% RPS Cases

As shown in Table 6 and Figure 2, the cost premium from the 20% RPS Reference Case to the 33% RPS Reference Case is 7.1%, or $3.6 billion more in the year 2020. Table 6 also shows that the cost impact of meeting a 33% RPS does not vary greatly between the High Out-of-State Delivered Case and the High-Wind Case. Statewide electricity expenditures under these cases are $1.5 billion and $1.7 billion lower than the 33% RPS Reference Case, respectively, with the cost savings largely resulting from replacing large quantities of solar thermal resources with less costly wind resources (see Figure 13 in Appendix B for the levelized cost of each generation technology). The cost similarity between the High Wind Case and the High Out-of-State Delivered Case indicates that remote wind resources can be constructed and delivered to California at a similar, though slightly lower, cost compared to building local resources, which are of lower quality and also require in-state transmission upgrades. On the other hand, the out-of-state resource costs could be even lower through trading RECs with no delivery requirement since the scenarios studied here all assume California deliverability and thus transmission investment.

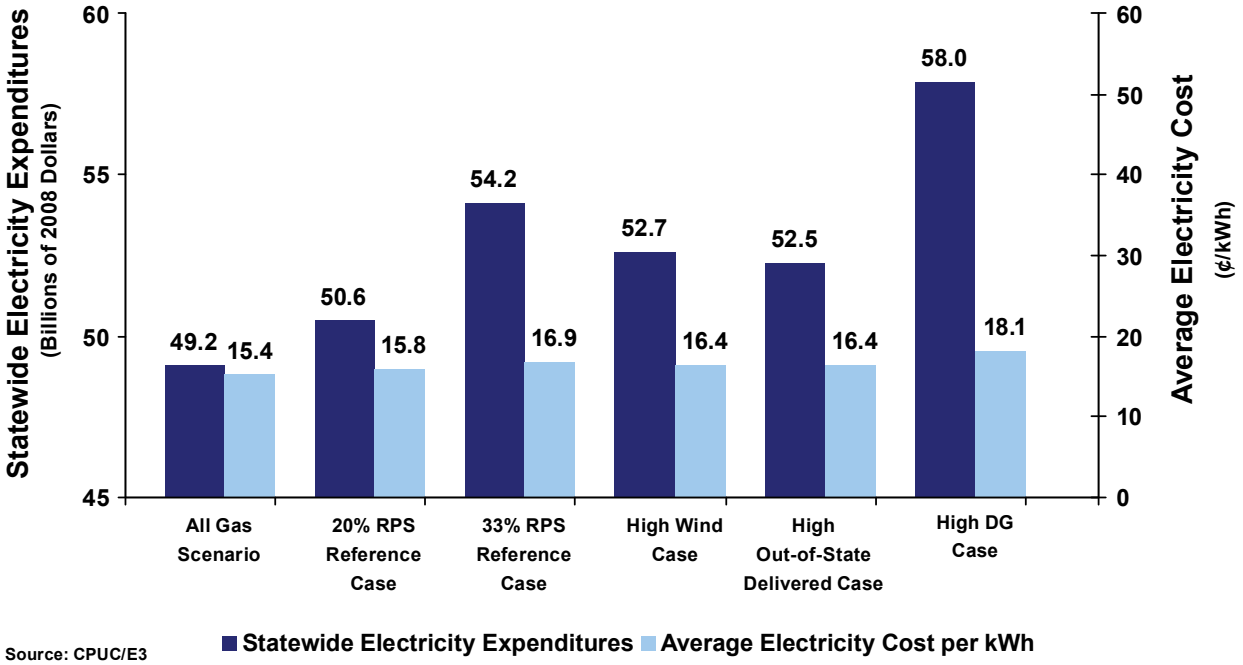
The cost impact of the High DG Case is significantly higher than the 33% RPS Reference Case, with a 14.6% cost premium compared to the 20% RPS Reference Case, and a 7% cost premium compared to the 33% RPS Reference Case. This is due to the heavy reliance on solar PV resources, which are currently much costlier than wind and central station solar.

Implication: The cost of a 33% RPS is higher than a 20% RPS under all four of the 33% RPS cases studied and the 33% RPS Reference Case is higher than all of the alternative RPS cases, except for the High DG Case.

Table 6. Costs and Cost Differences Between Alternative RPS Cases in 2020

Category	20% RPS Reference Case	33% RPS Reference Case	33% High Wind Case	33% High Out-of-State Delivered Case	33% High DG Case
Total Statewide Electricity Expenditures	$50.6	$54.2	$52.7	$52.5	$58.0
Average Statewide Electricity Cost	$0.158/kWh	$0.169/kWh	$0.164/kWh	$0.164/kWh	$0.181/kWh
Difference Relative to 20% RPS Reference Case	N/A	+$3.6	+$2.1	+$1.9	+$7.4
Percent Difference Relative to 20% RPS Reference Case	N/A	+7.1%	+4.2%	+3.8%	+14.6%
Difference Relative to 33% RPS Reference Case	N/A	N/A	-$1.5	-$1.7	+$3.8
Percent Difference Relative to 33% RPS Reference Case	N/A	N/A	-2.8%	-3.1%	+7.0%

Figure 2. Statewide Electricity Expenditures and Average Electricity Cost in 2020



Source: CPUC/E3

GHG Emission Reductions

This study only analyzed the GHG emissions associated with electricity generation and did not review the lifecycle emissions of each renewable technology, since that was beyond the scope of this analysis. The results indicate that a 33% RPS would reduce CO_2 emissions by approximately 29 million metric tons as compared to the all gas scenario, in which no new renewable projects are built after 2007. The CO_2 savings are similar for all of the 33% RPS cases, and are broadly consistent with the results of the GHG Calculator and the ARB analysis cited in the ARB Scoping Plan, which is 21.3 $MMTCO_2E$, despite differences in ARB's methodology for developing the 2020 baseline and a different set of electric sector CO_2 emission reduction measures.

SENSITIVITY OF RESULTS TO CHANGES IN INPUTS

In order to determine the sensitivity of the results to changes in key input assumptions, sensitivity analysis was conducted on the following factors: natural gas CO_2 allowance prices, higher levels of achievement of demand-side strategies such as energy efficiency and demand response, and the effect of a dramatic reduction in the installed cost of solar PV.

Natural Gas and CO_2 Price Sensitivity

The natural gas (gas) and CO_2 allowance price sensitivities are designed to test the results at the endpoints of a range of price expectations reflecting both the recent experience of price volatility and reasonable expectations.[20] Gas and CO_2 allowance prices are assumed to move together because increases in the price of either commodity will enhance the competitiveness of renewable resources by increasing the cost of fossil resources (relative to renewable generation) and reducing the overall cost impact of achieving a 33% RPS. Decreases in the cost of either commodity will have the opposite effect. The following endpoints were used to test effects of higher and lower gas and CO_2 allowance prices on the portfolios:

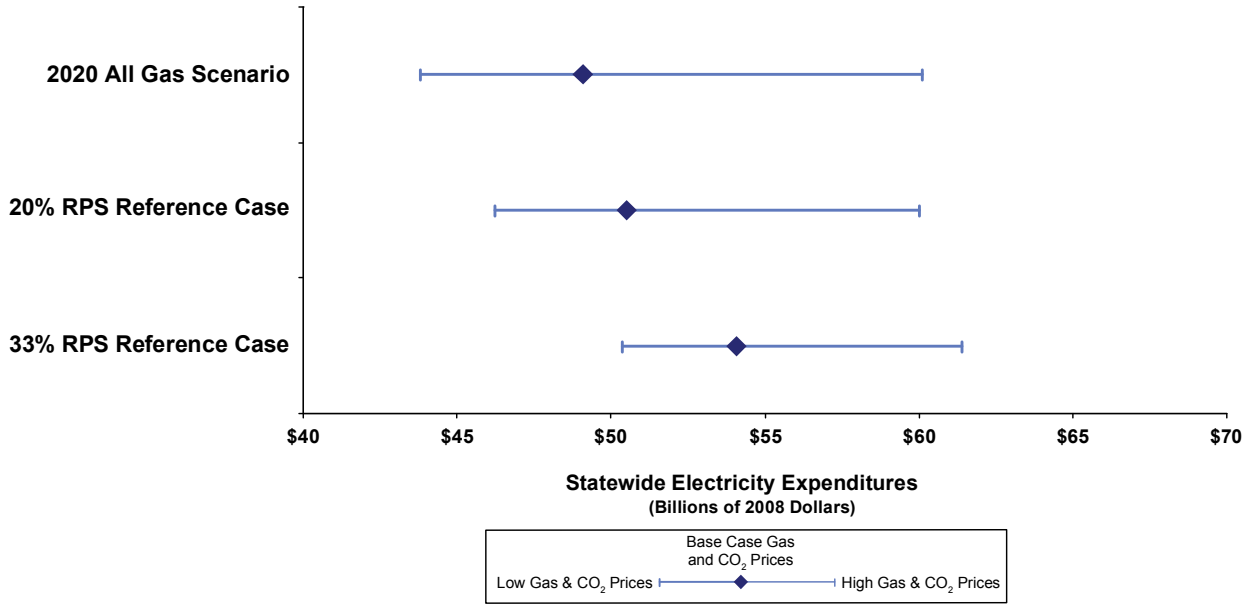
- **High Gas and CO_2 Allowance Prices:** 2020 gas price of $13.50/MMBtu at Henry Hub ($10.31/MMBtu in 2008 dollars delivered to California generators) and CO_2 allowance price of $100/tonne ($74.36 in 2008 dollars).
- **Low Gas and CO_2 Allowance Prices:** 2020 gas price of $6/MMBtu at Henry Hub ($4.74/MMBtu in 2008 dollars delivered to California generators) and CO_2 allowance price of $15/tonne ($11.15 in 2008 dollars).

These alternative assumptions were compared to the Base Case assumptions used in the RPS Calculator: 2020 gas price of $8.46/MMBtu at Henry Hub ($6.57/MMBtu in 2008 dollars delivered to California generators) and CO_2 allowance price of $42.46/tonne ($31.58 in 2008 dollars).[21]

[20] The high and low gas numbers are based on E3's expert judgment utilizing data from the Henry Hub over the past few years.
[21] Based on the Market Price Referent (MPR) methodology, see CPUC Decision 08-10-026

Figure 3 displays the range of statewide expenditures for the low, base, and high natural gas and CO_2 allowance prices. The range for the all gas scenario is $14.8 billion. The range of the 20% RPS Reference Case deceases to $12.5 billion and to $9.7 billion in the 33% RPS Reference Case. The alternative 33% RPS cases are not included in Figure 3 because their ranges are all approximately the same as the 33% RPS Reference Case.

Figure 3. Impact of Gas and CO_2 Allowance Prices on Statewide Expenditures



Implication: An increase in renewable energy penetration can decrease the range of statewide electricity expenditures by decreasing exposure to volatile fossil fuel prices. This could serve as a potential hedging strategy against volatile fossil fuel prices.

Impact of High Gas and CO_2 Allowance Prices

Figure 3 also shows that with High Gas and CO_2 allowance prices, the incremental cost of achieving the 33% RPS Reference Case is $1.7 billion or 2.9% higher relative to the 20% RPS Reference Case. This is substantially lower than the $3.6 billion or 7.1% cost impact under the Base Case Gas and CO_2 price assumptions.

Impact of Low Gas and CO_2 Allowance Prices

Under the Low Gas and CO_2 allowance prices, the incremental cost of achieving a 33% RPS compared to a 20% RPS is $4.5 billion, resulting in an increase of 9.7% relative to the 20% RPS Reference Case. However, it should be noted that while lower gas and CO_2 allowance prices raise the *relative* cost of achieving RPS goals, they exert a downward effect on electricity costs overall, such that overall electric costs are still lower under the Low Gas and CO_2 allowance

prices with 33% RPS than under the Base Case gas and CO_2 allowance price assumptions with a 20% RPS.

Figure 3 also shows that the statewide electricity expenditures for the all gas scenario are still not as high as the expenditures for the 33% RPS Reference Case, despite the decreased volatility. This means that gas prices would need to exceed $13.87/MMBtu and CO_2 allowance prices would need to exceed $100/tonne for renewable energy to be an effective hedge against fossil fuel prices at a penetration level of 33%.

Implication: While renewable energy can provide a hedge against volatile fuel prices, a 33% RPS provides an effective hedge only against a combination of very high natural gas and CO_2 allowance prices. Thus, the "hedging value" associated with resource diversity is not a very strong policy justification for establishing a 33% RPS.

Low-Load Sensitivity: Sensitivity of Results to Accelerated Demand-Side Goals

California's energy policy goals call for aggressive achievements of energy efficiency and demand response as well as high penetrations of renewable energy. Success in achieving energy savings through efficiency programs may result in lower costs of complying with a 33% RPS by reducing the amount of renewable projects required to reach the goal. A low-load scenario could also result from other factors, such as an economic slowdown.

A Low-Load sensitivity was developed to test the interactive effects between aggressive demand-side measures and a 33% RPS. The assumptions are based on the Accelerated Policy Case scenario presented in the GHG Calculator and described in the joint Energy Commission/CPUC Final Decision on Greenhouse Gas Regulatory Strategies.[22] The Accelerated Policy Case has lower electric demand and lower retail sales than the 2007 IEPR load forecast used in the 33% RPS Reference Case due to assumptions explained in Table 7.

[22] CPUC Final Decision on Greenhouse Gas Regulatory Strategies, D.08-10-037, Proceeding R.06-04-009, pp. 34 - 36.

Table 7. Assumptions in the 33% RPS Implementation Analysis Reference Cases Compared to the Low-Load Sensitivity

	20% and 33% RPS Reference Case	Low-Load Sensitivity
Energy Efficiency (EE)	Energy Commission load forecast assumes 16 TWh of embedded EE (80% of the CPUC's 2020 EE goals)[23]	'High goals' EE scenario from GHG Calculator based on CPUC Itron Goals Update Study: 37 TWh[24]
Customer-Installed Solar PV	Energy Commission load forecast, 847 MW nameplate of customer-installed PV[25]	3,000 MW nameplate of customer-installed PV
Demand Response	Energy Commission load forecast (no incremental demand response)	5% reduction in peak demand, no energy savings (capacity only)
Combined Heat and Power (CHP)	Energy Commission load forecast (no incremental CHP assumed)	1,574 MW nameplate small CHP 2,804 MW nameplate larger

The Low-Load sensitivity assumes that electricity load growth in California is reduced from 43 TWh in the 33% RPS Reference Case to 11 TWh due to aggressive demand-side policies, while peak load growth is reduced from 10,600 MW to 2,000 MW. Because of this reduction in projected 2020 retail sales, the RPS resources needed in the 33% RPS Reference Case are reduced from 75 TWh to 64 TWh in the Low-Load sensitivity. *In the absence of mitigating factors, this would be expected to result in a substantial reduction in the incremental cost of achieving a 33% RPS relative to a 20% RPS.*

However, Table 8 shows that the statewide incremental electricity expenditures of the 33% RPS Reference Case compared to the 20% RPS Reference Case is *higher* under Low-Load assumptions than under Base Case assumptions – $4 billion in incremental costs under Low-Load assumptions versus $3.6 billion under the Base Case load. This result is counterintuitive – all else being equal, one would expect the incremental costs of the Low-Load sensitivity to be lower since it requires a smaller quantity of renewable generation. Further exploration is required to determine the cause of this counterintuitive result.

[23] The Energy Commission assumed the remaining 20% of the 2020 EE goals impacts were "uncommitted," and therefore excluded from the state's official forecast. In D.07-12-052, the CPUC assumed that 100% of the 2020 EE goal impacts would be realized for procurement purposes. The Energy Commission load forecast does not take into account the Big Bold goals the CPUC established in D.07-10-032.
[24] This scenario does not take into account the Big Bold goals the CPUC established in D.07-10-032.
[25] The 2007 IEPR load forecast assumed 847 MW of customer-side PV, a fraction of the 3,000 MW California Solar Initiative goal.

Table 8. Statewide Electricity Expenditures in 2020 for the 20% and 33% RPS Reference Cases Under the Low-Load Sensitivity (billions of 2008 dollars)

Costs	Base Case Loads	Low-Load Sensitivity
Total Electricity Expenditures, 20% RPS Reference Case	$50.6	$46.4
Total Electricity Expenditures, 33% RPS Reference Case	$54.2	$50.4
Incremental cost of 33% RPS Reference Case	$3.6	$4.0
Percent Difference Relative to 20% RPS Reference Case	7.1%	8.6%

Table 9 shows the net qualifying capacity[26] of all resources added for the 20% and 33% Reference Cases under both the Base Case and Low-Load sensitivity. After considering peak demand growth, an assumed 17% planning reserve margin, and the need to replace generators using once-through cooling, the total need for new capacity is 19,022 MW. Demand-side achievements reduce the needed capacity to 9,053 MW under the Low-Load Sensitivity.

Exactly 19,022 MW of capacity is added under the 20% Reference Case. However, 21,002 MW of capacity is added under the 33% RPS Reference Case, resulting in a capacity surplus of 1,980 MW. *This occurs because of the timing challenges of adding new renewables.* The model adds conventional resources to meet demand growth in the early years, before most of the renewable resources are online. The addition of large quantities of new renewables in the later years results in a temporary capacity surplus. The 2020 surplus is relatively small – 1,980 MW – under Base Case load growth assumptions. However, the surplus amounts to ***5,313 MW*** under the Low-Load sensitivity.[27] *Under the Low-Load sensitivity, the pace of required renewable resource development is so rapid compared to load growth that a substantial surplus of capacity is all but unavoidable.*

Under the 20% RPS Reference Case, demand-side programs result in substantial avoided capacity investments, or capacity savings. However, avoided capacity investments from demand-side programs are reduced under the 33% RPS Reference Case and dramatically reduced under the Low-Load sensitivity. This reduced savings from avoided capacity investments outweigh cost savings resulting from decreased renewable energy procurement. This causes the incremental cost of the 33% RPS Reference Case to be higher under the Low-Load sensitivity than under the Base Case load growth assumptions.

Note that this effect is due strictly to the need to procure *capacity* to meet peak demand requirements, and it occurs irrespective of the *energy* benefits of new renewables. It is possible that this peak capacity surplus could allow earlier retirement of fossil peaking generators. However, further study would be required to identify candidate generators and ensure that they

[26] Net qualifying capacity is the capacity value of the resource that can be counted toward resource adequacy requirements. This value is equal to the nameplate capacity for thermal generators, but is based on expected output during peak periods for intermittent renewable resources.

[27] Note that this analysis likely understates this effect, because renewable resource integration costs were treated as a simple, $/MWh adder. If new conventional resources are required to integrate wind and solar generation, the resulting capacity surplus would be larger under the 33% RPS cases.

are not needed to meet local reliability requirements or to ensure reliable system operations while integrating thousands of megawatts of new intermittent renewables.

Table 9. 2020 Capacity Balance Under the 20% and 33% RPS Reference Cases for the Base Case and Low-Load Sensitivity Load Growth (MW)

2020 Capacity Need, Additions, and Surplus	Base Case Loads		Low-Load Sensitivity	
	20% RPS Reference Case	33% RPS Reference Case	20% RPS Reference Case	33% RPS Reference Case
Growth in Peak Demand, 2008-2020	10,602	10,602	2,082	2,082
Additional Capacity Needed to Meet 17% Planning Reserve Margin[28]	1,802	1,802	354	354
Cumulative Retirements of Once-Through Cooling Generators[29]	6,617	6,617	6,617	6,617
Required Additions in Dependable Capacity	***19,022***	***19,022***	***9,053***	***9,053***
Dependable Capacity From New Renewables[30]	4,604	13,024	3,243	11,352
Capacity Added From Once-Through Cooling Repowering[31]	2,883	2,883	2,883	2,883
Cumulative Combustion Turbines and CCGTs Added for Resource Adequacy[32]	11,535	5,095	2,927	131
Total Capacity Additions	***19,022***	***21,002***	***9,053***	***14,366***
Capacity Surplus[33]	**0**	**1,980**	**0**	**5,313**

Implication: If the state does not plan for interactions between energy efficiency, fossil retirements, and a 33% RPS, then a 33% RPS by 2020 could result in a surplus of energy or capacity and excess consumer costs. This interplay highlights the need to analyze and plan for interactions among the state's various policy goals. An integrated approach is needed to ensure that policy goals result in a resource plan that effectively furthers the important, underlying policy objectives and produces an efficiently integrated electricity system at an acceptable cost.

[28] Calculated as 17% of peak demand growth
[29] Based on a high-level analysis of once through cooling generators that are candidates for retirement
[30] Based on summer, peak period net qualifying capacity values, available at http://www.caiso.com/202f/202f9a882ec90.xls
[31] These generators are assumed to be needed to meet local reliability requirements, and are therefore the same in all cases.
[32] Remaining resources needed to meet resource adequacy requirements
[33] There is a capacity surplus in 2020 in the 33% RPS Reference Case because conventional resources are required to meet load growth in the early years, before the renewables can come online.

This result highlights the need for coordination among demand-side and supply-side programs to ensure compatibility and efficiency. For example, if the RPS portfolio is likely to result in substantial penetration of new solar thermal resources with storage, the resulting capacity surplus would reduce the need for demand response. Alternatively, if the RPS portfolio is heavy in wind resources that produce mostly at night, efficiency programs that target night time energy use such as outdoor lighting programs would be substantially less valuable. These interactions also depend strongly on the timing of new resource development; implementing California's aggressive energy policy goals over a longer period of time would reduce the likelihood of negative interactions among the various programs because programs could be adjusted along the way more easily.

Solar PV Cost Reduction Sensitivity

The Solar PV Cost Reduction sensitivity explores the impact of lower solar PV costs on the cost of meeting a 33% RPS. The solar energy industry is currently small relative to other renewable technologies, and technological innovations continue to improve solar PV's performance and reduce the cost of manufacturing. The solar PV industry expects that continued technological improvements and economies of scale will substantially reduce the cost of solar technology by 2020. The pace of such innovation is highly uncertain, however, and the delivered cost of energy depends on a number of other factors besides the manufactured component cost, not least of which is the continued willingness of the federal government to grant generous tax incentives, such as the investment tax credit. Despite this uncertainty, it is helpful to consider how solar PV innovation might change the cost impacts of a resource mix with high solar PV penetration.

The Solar PV Cost Reduction sensitivity is based on the thin-film cost sensitivity included in the RETI Phase 1B report,[34] and assumes that market transformation reduces the installed cost from approximately $7/Watt-equivalent (W-e)[35] today for crystalline solar PV to $3.70/W-e for thin-film solar PV by 2020. RETI derived this number from goals and cost targets that solar PV manufacturers and developers provided. This assumption lowers the delivered energy cost of a typical solar PV facility from $306/MWh to approximately $168/MWh. These cost reductions were modeled as a *sensitivity*, meaning that the impact of the cost reductions were simply calculated on the High DG and 20% RPS and 33% RPS Reference Cases.

The impact of this sensitivity is presented in Figure 4. As a result of the assumed cost reductions, statewide electricity expenditures decrease by $4.6 billion under the High DG Case and by $1.9 billion under the 33% RPS Reference Case. Statewide electricity expenditures are $53.4 billion under the High DG Case and $52.3 billion under the 33% RPS Reference Case. Thus, the Solar PV Cost Reduction sensitivity results in the High DG Case having similar overall costs to the 33% RPS Reference Case and other renewable resource mixes that depend on central station renewable generation.

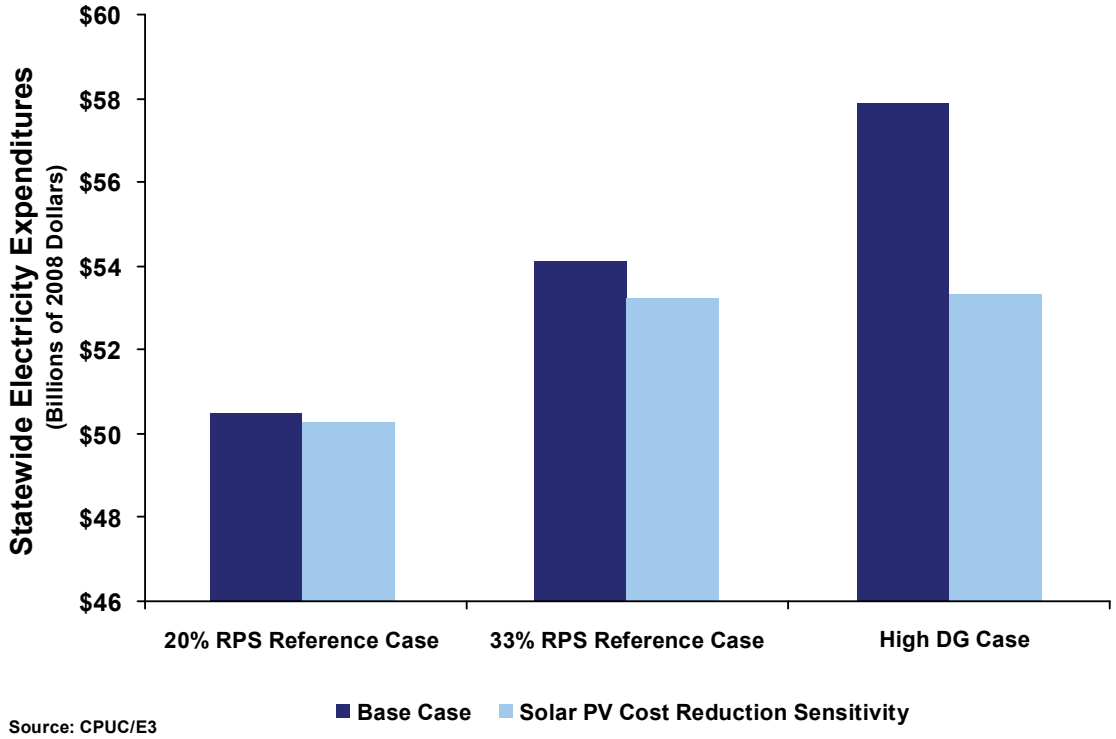
[34] The RETI Phase 1B report is available at: http://www.energy.ca.gov/2008publications/RETI-1000-2008-003/RETI-1000-2008-003-F.PDF

[35] Watt-equivalent is a term used for solar PV that refers to grid-equivalent Watts after considering DC-AC conversion losses. $7/Watt-equivalent corresponds to approximately $5.83/nameplate Watt, and $3.70/W-e corresponds to $3.08/nameplate Watt.

These study results, however, are uncertain and come with a number of caveats. First, and most importantly, the thin-film sensitivity number used is very aggressive and the distributed solar PV technical potential estimates are not based on an engineering analysis. Second, there was no detailed analysis conducted of the cost difference of developing solar PV at various sizes and locations. Instead, rooftop solar PV was assigned an 8% cost premium and a 21% capacity factor penalty relative to ground-mounted solar PV. Third, simple, high-level assumptions were made about the distribution and transmission costs – or savings, depending on location – associated with interconnecting solar PV. Fourth, an implementation analysis of integrating such high levels of solar PV on the distribution system was not included in the analysis. Finally, the solar PV industry is still relatively small (though growing rapidly), and there is some question whether the solar PV industry can manufacture and supply the equipment at this level without leading to supply-chain constraints. A next step could be to conduct an implementation analysis on the market and regulatory barriers associated with the levels of solar PV in the High DG Case.

Implication: If solar PV experiences significant cost reductions, then a renewable portfolio with substantial quantities of solar PV could be much more cost-effective compared to today's solar PV market prices. The cost-effectiveness of the overall portfolio will depend on the program delivery costs; the High DG Case only uses the technology cost of solar PV, and not the deployment or program implementation costs, which would be higher due to significantly higher transaction costs to deploy thousands of solar PV projects.

Figure 4. Cost Savings Due to Solar PV Cost Reduction Sensitivity



Source: CPUC/E3

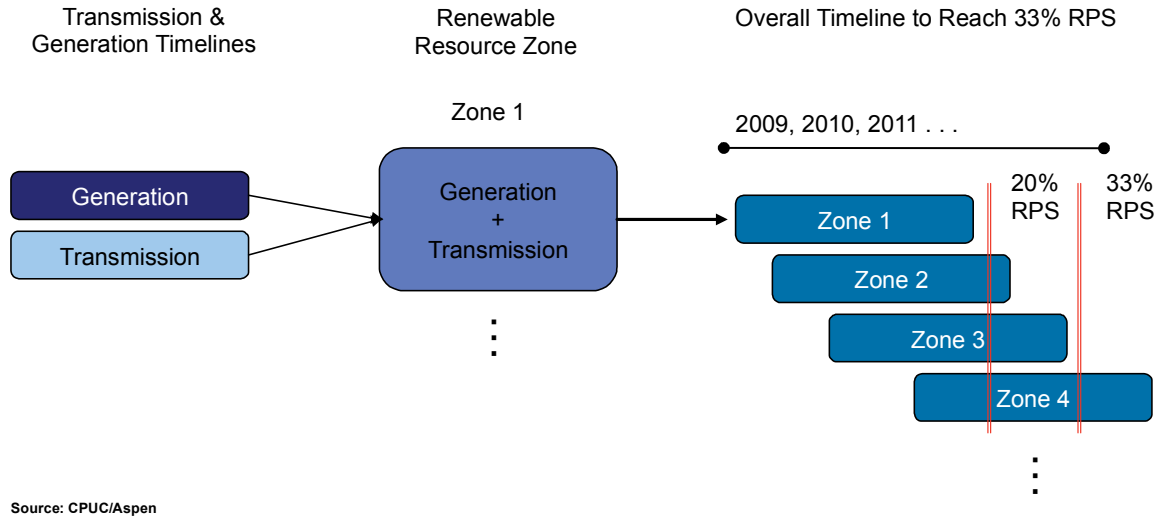
4 33% RPS Reference Case Illustrative Timelines

This section addresses the question of timing: whether the renewable generation and transmission needed for a 33% RPS can be built by 2020. Through the analysis described in this section, CPUC staff sought to understand the nature of the generation and transmission resources needed over time and the impact of ongoing reforms on the development of those resources, to identify areas where further reform is needed, and to understand the potential impacts of various risks on progress towards the 33% RPS goal.

To simplify this timeline analysis and to evaluate California's current resource contracting path, only the time and implementation challenges associated with the development of the 33% RPS Reference Case were evaluated. This section identifies some of the factors that could affect the timing of the generation and transmission development in the 33% RPS Reference Case, and thus the date by which the state could reasonably expect to reach a 33% RPS.

In order to construct illustrative timelines for the 33% RPS Reference Case, the project team first created generic timelines that estimate the permitting and construction times for generation projects – by technology, size, and permitting jurisdiction – and for transmission projects. These generic generation and transmission timelines were then used to create timelines for each resource zone selected in the 33% RPS Reference Case. Finally, the resource zone timelines were combined to create an overall timeline for the 33% RPS Reference Case. Those generation projects in the Reference Case that are *not* dependent on new in-state transmission were assumed to be developed in parallel with the "zone" resources, so that the 33% RPS is achieved with the full development of the last zone. Figure 5 illustrates this process.

Figure 5. Process for Developing 33% RPS Reference Case Timelines



INDIVIDUAL RESOURCE ZONE TIMELINES

In order to quantify the time needed to develop all the transmission and generation required in the 33% RPS Reference Case, individual timelines were developed for each of the resource zones included in the 33% RPS Reference Case, using the methodology and generation and transmission timelines described in Appendix B. The resource zones that need new transmission are listed in Table 10. In some cases, two resource zones can share one major transmission project.

Table 10. Renewable Resource Zones that Need New Transmission for 20% and 33% RPS Reference Cases

Resource Zone	MW	GWh
Included in 20% and 33% RPS Reference Cases		
Tehachapi	3,000	8,862
Solano	1,000	3,197
Imperial North	1,500	9,634
Riverside East	1,350	3,153
Included in 33% RPS Reference Case Only		
Riverside East (incremental)	1,650	3,869
Mountain Pass	1,650	4,041
Carrizo North	1,500	3,306
Needles	1,200	3,078
Kramer	1,650	4,226
Fairmont	1,650	5,003
San Bernardino - Lucerne	1,800	5,020
Palm Springs	806	2,711
Baja	97	321

Transmission and Generation Development in a Resource Zone

Because of its longer development horizon, transmission is nearly always the critical path item in the development of a zone. Speeding the approval and development of transmission projects would thus facilitate earlier development of resource zones. This result is already well understood in California, and significant efforts are underway at both the state and federal level to expedite the review, planning, and permitting of appropriate transmission lines to support delivery of renewable resources.

Generation projects in California are subject to environmental review and permitting by county, state, or federal agencies, depending on the project's technology type, size, and location (see Figure 15 in Appendix B for a description of these categories and permitting jurisdictions). Table 11 shows how the generation projects in the 33% RPS Reference Case are distributed among permitting jurisdictions. Although this distribution is particular to the set of resources chosen for the 33% RPS Reference Case, the table gives a sense of the order of magnitude of the permitting required under any 33% RPS portfolio.

Table 11. Permitting Jurisdiction for Generation Projects in the 33% RPS Reference Case

Jurisdiction	Number of Generation Projects
Solano County	9 projects
Kern County	10 projects
Imperial County	7 projects
Riverside County	11 projects
Los Angeles County	13 projects
San Bernardino County	16 projects
San Luis Obispo County	6 projects
Energy Commission (sole or joint)	30 projects
Bureau of Land Management or Other Federal Agency (sole or joint)	46 projects in California (mainly Southern CA) 2 projects in Baja (Presidential Permit) 21 projects other Out-of-State or International Imported

Implication: The number of projects that may require review and approval by these jurisdictions now and in the coming years highlights the need for a major increase in trained specialists and staffing and consulting resources to process these permit applications within the timeframe of a 33% RPS by 2020.

Transmission and Generation Timing Considerations

Some delay is generally expected between completion of a transmission line and full use of that line. This delay results from the generation developer's need for certainty about transmission availability before investing capital into project development activities. Assuming that renewable generation developers will not begin construction until a final permit for the required transmission line is issued,[36] all generation projects in a renewable zone would have to complete construction in parallel with the construction of the transmission line in order to avoid the generation-transmission time lag. Such rapid and simultaneous generation development seems unlikely, particularly in the case of capital-intensive technologies like solar thermal and geothermal.

This situation may be exacerbated in California in the next few years because of the amount of generation that is dependent on new transmission and that must come online quickly. For example, if multiple generators in a renewable resource zone are dependent on one major transmission project, and they all plan their project development schedules around estimates of that transmission's availability, they may all enter the permitting phase at the same time, potentially overloading the relevant permitting authority and leading to delays in the issuance of

[36] Generators are often not able to secure full financing until transmission assurance is received. Without financing, many generators will not be able to move far into the permitting process, leaving even more work to be done after the transmission permit is issued.

site permits. For instance, the illustrative San Bernardino-Lucerne resource zone in Figure 6 includes many projects requiring Bureau of Land Management (BLM) and Energy Commission approval, and concurrent permitting of all projects could prove to be a challenge.

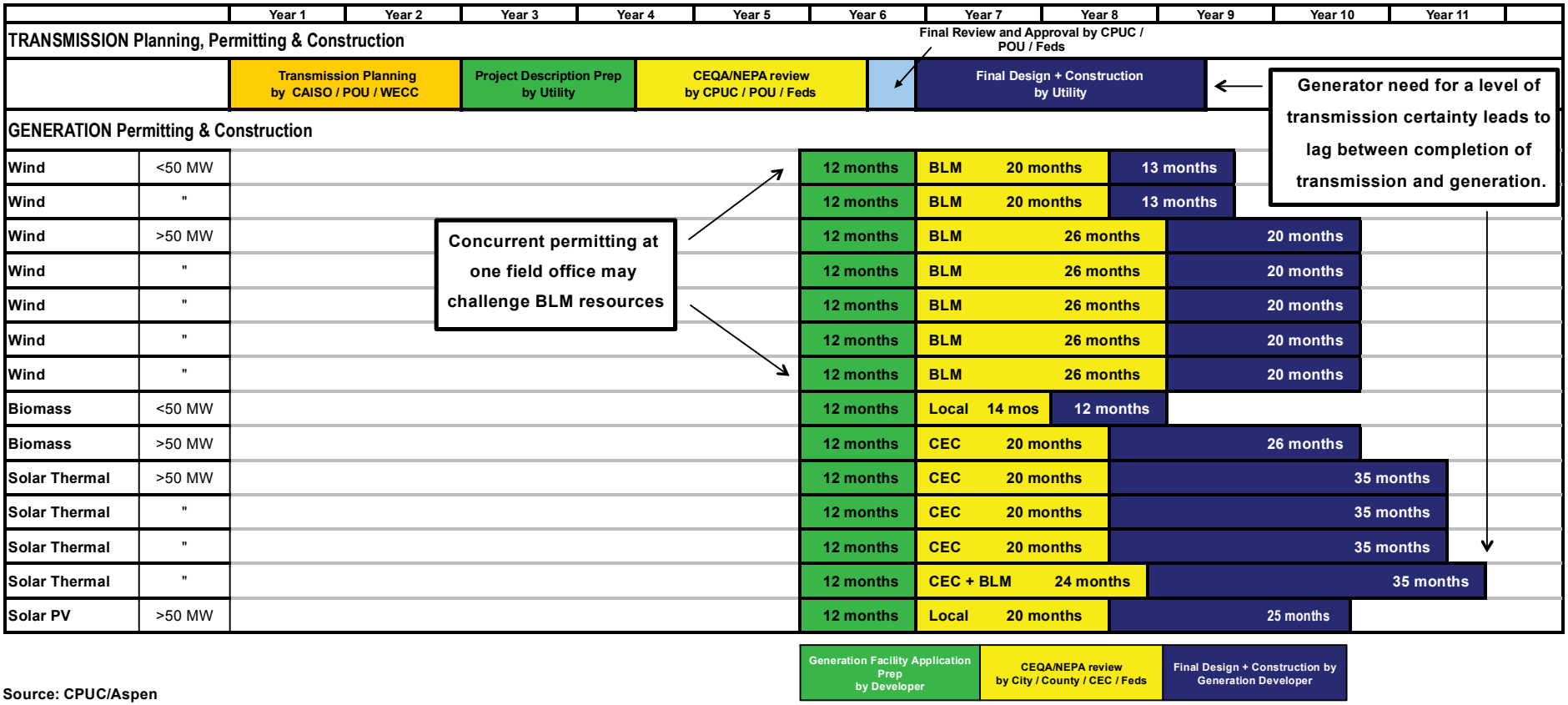
Implication: The interaction between transmission and generation time lag can be a significant source of time delay. State and federal agencies should focus on ensuring that permitting agencies are prepared to process large numbers of generation applications in a timely manner, particularly in areas where new transmission is expected or already permitted.

Figure 6 presents an illustrative timeline for the San Bernardino-Lucerne resource zone and demonstrates how the timelines for a mix of renewable generation projects and one major new transmission line are combined to provide an overall timeline for the development of that resource zone. This zone timeline also highlights the interaction between the timing of transmission and generation development that can result in a lag between transmission completion and full utilization of that line.

Figure 6 Timeline Assumptions:

- Individual generation projects in this zone are those included in the 33% RPS Reference Case; one major new transmission line and perhaps some smaller lines would be needed to access and deliver the required amount of generation.
- Generation and transmission timelines are based on the generic timelines described in the Methodology (Appendix B). They reflect recent experience with actual projects.
- Development of generation begins one year before final approval of the required transmission line because of the need for a degree of certainty regarding transmission availability to facilitate generation project financing.

Figure 6. Example of Generation and Transmission Timelines Combined to Create a Resource Zone Timeline (San Bernardino – Lucerne Resource Zone)



Source: CPUC/Aspen

Result: The transmission in this zone takes longer to develop than the generation. However, the generation developers' need for a degree of certainty regarding transmission availability in order to obtain financing and invest in project development causes them to delay project development until several years into the transmission development process. This results in a 29-month period between completion of the transmission and full development of the zone.

ILLUSTRATIVE TIMELINES FOR THE 33% RPS REFERENCE CASE

Following the completion of timelines for each of the zones in the 33% RPS Reference Case, the resource zone timelines were combined to create an overall timeline for the 33% RPS Reference Case. CPUC staff adapted this overall 33% RPS timeline to depict three scenarios using the distinct sets of assumptions presented in Table 12. Timeline 1 depicts the state's relatively recent historical experience in transmission and renewable development, but does not include process reforms or external risks. Timeline 2A and 2B reflect the possible effects of the state's current and ongoing reforms to expedite and streamline the permitting and review processes. Unlike Timeline 2A, Timeline 2B considers the possible effects of external risks that could undermine the efforts at reform. Timeline 2A is not realistic or plausible since it does not include external risks, but rather provides a reference point upon which Timeline 2B is built.

Table 12. Description of Illustrative Timelines for the 33% RPS Reference Case

Timeline	Description
Illustrative Timeline 1: Historical experience without process reform	This scenario is based on the state's experience with generation and transmission development over the last 10-15 years. Timeline assumes transmission planning, permitting, and construction processes that are almost entirely sequential.
Illustrative Timeline 2A: Current practice with process reform and no external risks	Development trajectory if California successfully implements transmission and generation reforms that are already underway. Timelines are unrealistic because they assume no delays from external factors that are not addressed by current reforms.
Illustrative Timeline 2B: Current practice with process reform and external risks	Development trajectory if state successfully implements reforms, but factors outside the direct control of state agencies, such as technology failure, financing difficulties, and legal challenges, cause delay or failure of some projects necessary to achieve the 33% RPS Reference Case.

Several assumptions are common to all of the timelines:

- For purposes of this timeline analysis, "achievement of the 33% RPS target" implies achievement of the full 33% RPS Reference Case buildout, which was developed to serve 33% of 2020 retail sales. The 33% RPS Reference Case is not updated to account for expected load growth after 2020 that would cause the 33% RPS target, an energy and not a capacity goal, to increase slightly every year, even though, in all of the timelines, the 33% RPS goal is not achieved until after 2020.
- A delay of 30 months – an approximation of the delay depicted in Figure 6 – is assumed to occur between transmission completion and full generation buildout in all scenarios, since California has not yet implemented processes that would address this delay.
- The resource zones in the 20% RPS Reference Case (the zones at the top of each timeline) are assumed to be accessed by actual transmission projects that are already in some late stage of development or are otherwise expected to have shorter development timelines due to jurisdiction and location.

- Development horizon for the Baja zone (Zone 6) is constant in all three scenarios, as it would be only minimally affected by the California process reforms assumed in Timelines 2A and 2B.
- No specific generation is associated with the Path 15 upgrade, but this upgrade was identified as likely needed to maintain reliability under the 33% RPS Reference Case, given the large amount of generation added in Southern California, relative to Northern California. The assumed short time horizon reflects transmission planning efforts now underway. Other upgrades will no doubt be needed to maintain system reliability; this analysis did not attempt to identify all of those upgrades.

ILLUSTRATIVE TIMELINE 1: HISTORICAL EXPERIENCE WITHOUT PROCESS REFORM

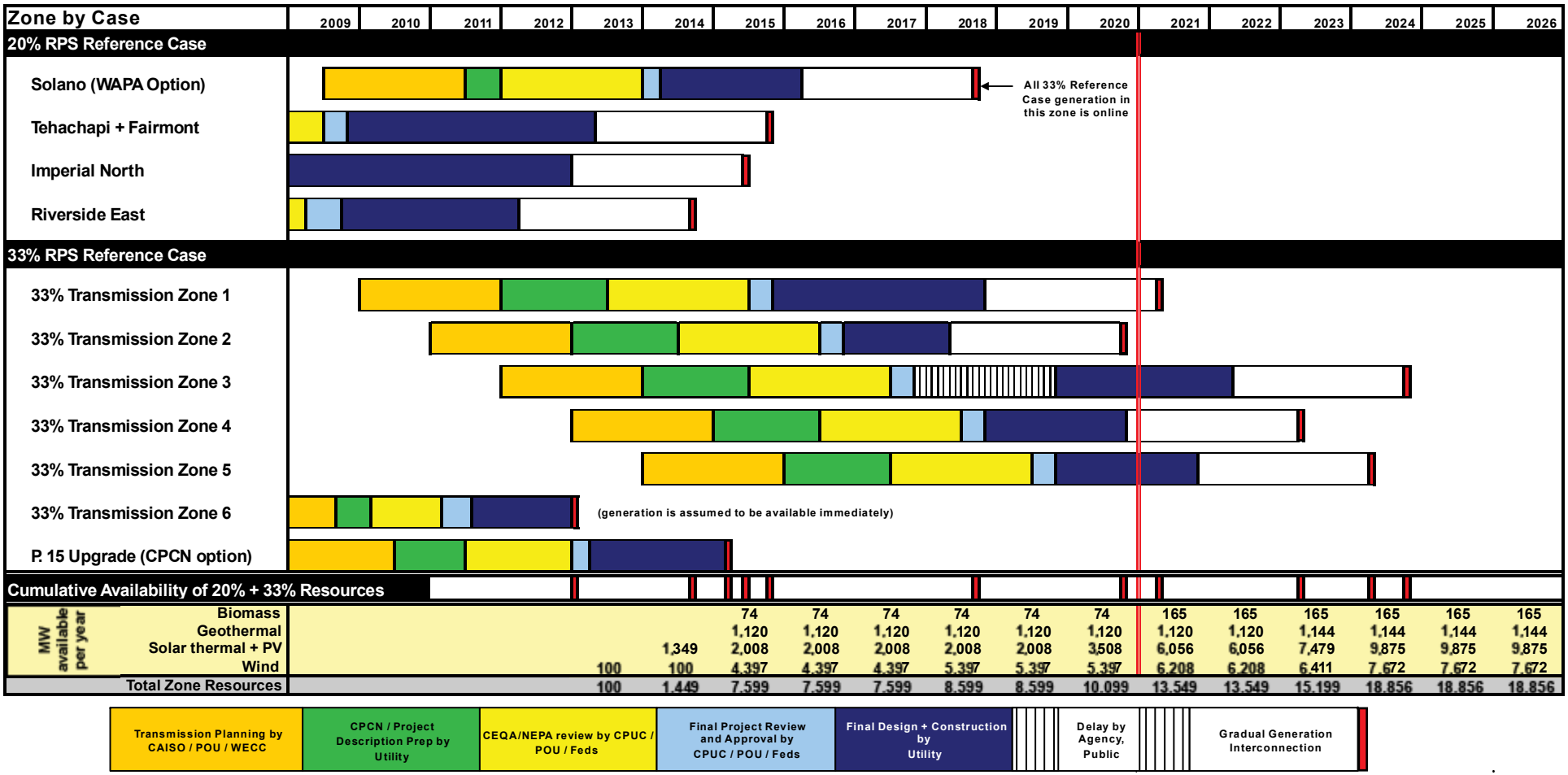
Timeline 1 (Figure 7) reflects the timeline for achieving the 33% RPS Reference Case under the "historical experience without process reform" scenario. The purpose of this timeline is to demonstrate the time savings achieved if current and ongoing process reforms are successful. Under this scenario, the 33% RPS Reference Case is achieved in 2024. Because the 33% RPS Reference Case closely mirrors California's recent renewable resource development path (as represented through IOU contracts), this timeline indicates that the state would be unlikely to meet a 33% RPS by 2020, if past transmission planning and permitting processes and the associated transmission-generation time interactions were to continue. This timeline does not assume any external risks, such as those associated with Timeline 2B (Figure 9), so this timeline is not realistic.

Timeline Assumptions:

- Timelines for each phase of the generation and transmission development processes are based on California experience over the last 10-15 years.
- Transmission planning, permit preparation, environmental review, and final project design/construction happen in sequence, with very little overlap.
- One new transmission project enters the development process each year, starting in 2009. Timelines are shortened in cases where real transmission projects already in some stage of development would access a zone identified in the 20% or 33% RPS Reference Cases.
- One significant, two-year delay is assumed for the transmission project needed to access Zone 3. Based on recent experience, such a delay could result from permitting delays at a federal agency, or other factors. This delay is assigned randomly for illustrative purposes only, and does not relate to any specific concerns anticipated with Zone 3. The purpose of the delay is to illustrate that the delay of any transmission project, regardless of which one, significantly impacts the 33% RPS schedule.
- Beyond one 2-year delay to a transmission project's construction, *Timeline 1 assumes none of the other external delays that are considered in Timeline 2B.*

Implication: California must implement changes to its transmission and generation planning and permitting processes now to achieve a 33% RPS by 2020. Several critical reforms have already been implemented, and several more are in the early stages of development and implementation. Timeline 1 reflects empirical experience in California to date, and highlights how crucial it is that the process reforms now underway in California be implemented successfully.

Figure 7. Illustrative Timeline 1 for the 33% RPS Reference Case: Historical Experience Without Process Reform



Source: CPUC/Aspen

Result: The 33% RPS Reference Case is achieved in 2024, assuming no external risks.

Note: While the CPUC averages approximately 18 months for California Environmental Quality Act review and Certificate of Public Convenience and Necessity approval for transmission siting cases in general, more conservative assumptions were used here to account for the likely larger and more controversial nature of these new required projects.

ILLUSTRATIVE TIMELINE 2A: CURRENT PRACTICE WITH PROCESS REFORM AND NO EXTERNAL RISKS

Timeline 2A (Figure 8) reflects the timeline for achieving the 33% RPS Reference Case under "current practice with process reform and no external risks." The purpose of this timeline is to provide a reference point to show the effects of process reforms without the potential undermining effects of any external risks not within the state's control. This timeline assumes the full implementation of several process reforms instituted at California agencies and other entities within the last three years, as well as successful implementation of other reforms that are now only in the early stages of development and implementation.

Timeline Assumptions:

- Reflects successful implementation of the significant process reforms currently underway at the California ISO and the CPUC. These reforms, which are described in this section, are administrative in nature and do not require any changes to existing law.
- Two new transmission projects enter the development process in 2010 as a result of RETI, the California ISO's Generation Interconnection Process Reform, and other processes, with one major renewable transmission project beginning development each year between 2011 and 2013.
- The two-year delay assumed in Timeline 1 for the transmission project needed to access Zone 3 is removed since this timeline is meant to show only the effects of process reform. Assumes no resource constraints in processing transmission and generation permitting applications.
- All of the transmission lines needed for the 33% RPS are assumed to involve the California ISO planning process, rather than a planning process at a publicly-owned utility (POU). This assumption is applied to simplify the presentation of the timing of transmission planning. Although a mix of POU-and California ISO-controlled lines will likely be developed, this assumption is not unreasonable, given the California ISO's responsibility for planning and operating most of the state's grid.
- *Timeline 2A assumes none of the other external delays that are beyond the state's control. These risks are factored into Timeline 2B.*

Timeline 2A indicates that the generation and transmission infrastructure required for a 33% RPS could be developed by 2021 with the successful implementation of these reforms, assuming no external delays (those outside the direct control of the state). The 33% RPS is achieved three years earlier in Timeline 2A than in Timeline 1. While Timeline 2A is likely unrealistic since it assumes no risks beyond those addressed by these reforms, it highlights the importance of current efforts underway to reform planning and permitting processes. Timeline 2B will show the potential impact of external risks, those outside of the state's control, on the gains realized through the reforms highlighted in Timeline 2A.

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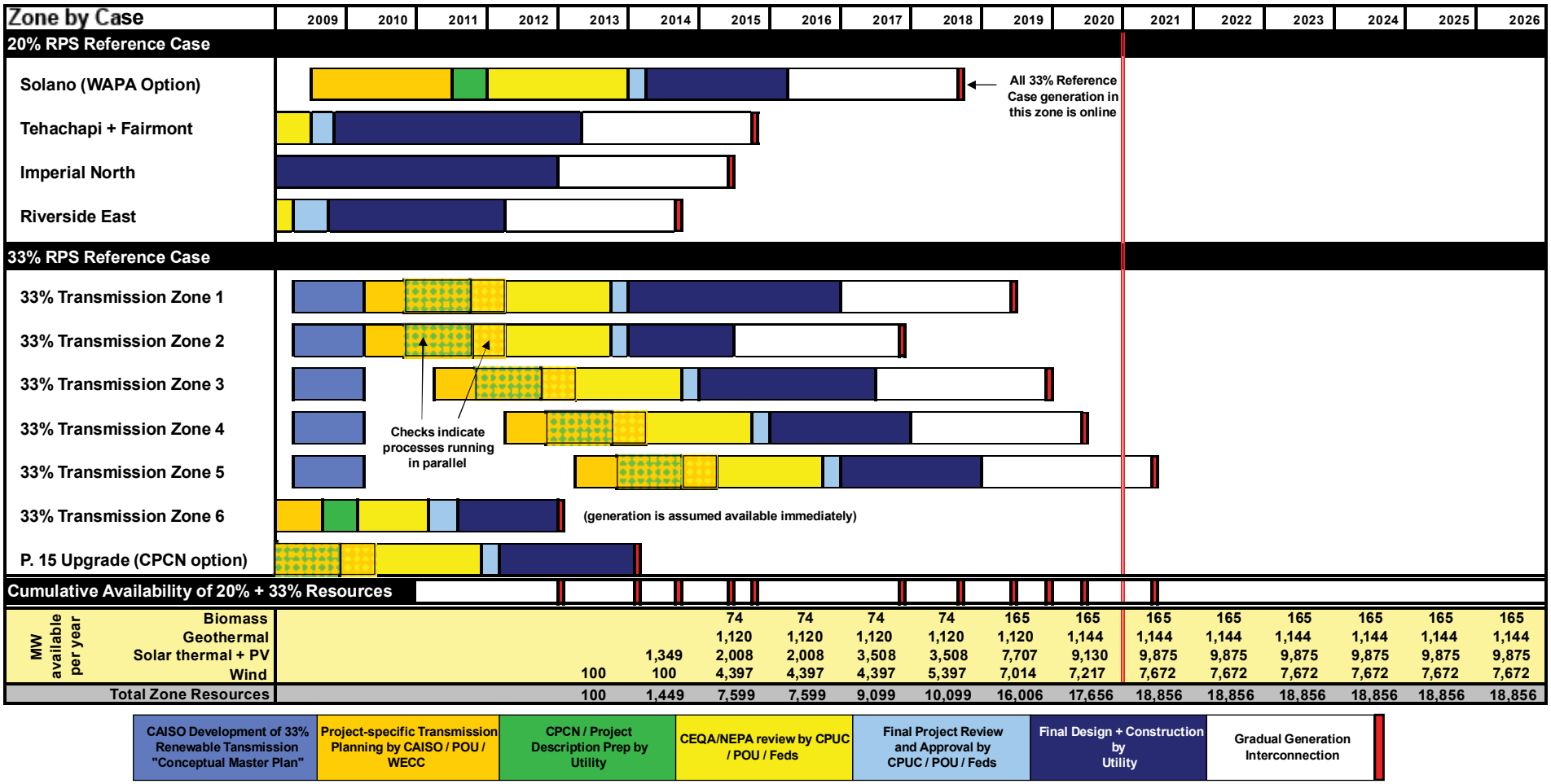
Implication: Efforts underway to reform generation and transmission planning and permitting processes could significantly speed the rate at which California is able to achieve a 33% RPS.

Figure 8. Illustrative Timeline 2A for the 33% RPS Reference Case: Current Practice With Process Reform and No External Risks



Source: CPUC/Aspen

Result: The 33% RPS Reference Case is achieved in 2021, assuming no external risks that could result in delay.

DESCRIPTION OF REFORMS EMBEDDED IN TIMELINES 2A AND 2B

Development of the generation and transmission infrastructure required for a 33% RPS could be achieved by 2021 with the successful implementation of the significant process reforms discussed here, assuming there are no external delays – those outside the direct control of the state. California planning and permitting entities must give high priority to process improvements today. Given the long lead times needed to develop transmission and generation projects, a delay of even a year or two may hinder the state's ability to reach its renewable goals in time.

Reform 1: Improvements to California ISO Procedures for Interconnecting Generation Facilities

The California ISO has recently implemented two very important reforms that will help expedite generator interconnection to the transmission grid. The Generation Interconnection Process Reform (GIPR) has increased the speed and efficiency of studying interconnection requests by planning common transmission solutions for groups of generation projects and integrating such planning into the California ISO annual transmission planning process. In addition to projects in the "serial" study group[37] that are nearing study completion, GIPR intends to complete its first set of interconnection cluster studies by the second quarter of 2010, which will help clear much of the existing transmission interconnection request backlog. The California ISO's new Location-Constrained Resource Interconnection process is the second reform that is expected to help renewable generators. This process provides a framework for planning and sharing the costs of large transmission facilities that interconnect location-constrained renewable resource areas. In May 2009, the California ISO applied this cost-sharing mechanism for the first time to an interconnection that will access renewable generation in the Tehachapi wind resource area.

- The GIPR and Location-Constrained Resource Interconnection reforms contribute to the 2-year planning process assumed in Timelines 1, 2A, and 2B.

Reform 2: Streamlining Transmission Permitting

The siting of a transmission line includes the review required under the California Environmental Quality Act (CEQA) – at least one full year of environmental studies – as well as a determination that the line is needed, through the issuance of a Certificate of Public Convenience and Necessity (CPCN). The CPUC is working to streamline all aspects of this process, while considering fully the environmental and economic impacts of any proposed project.

CEQA Review

In 2006, the CPUC issued directives[38] that streamline the pre-filing, post-filing, and proceeding phases of the transmission permitting process. CPUC staff makes use of streamlining tools such as project-specific memoranda of understanding with federal agencies and mitigated negative declarations whenever possible. In 2008, CPUC staff prepared streamlining recommendations to address and clarify the complex mitigation issues associated with permitting and constructing new transmission. In 2009, the CPUC initiated a series of workshops to be held every 6-9

[37] The "serial group" consists of generation projects that, for a number of reasons, continued in the serial study process that characterized the interconnection process prior to the adoption of the Generation Interconnection Process Reform's cluster study approach.

[38] ftp://ftp.cpuc.ca.gov/puc/energy/environment/060713_transmissionprojectreviewstreamliningdirective.pdf

months with state and federal resource agencies to facilitate better coordination on permitting, considering staffing shortages and increasing workloads. Further, through close coordination during the pre-filing phase, CPUC staff aims to streamline the CPUC's environmental review by ensuring that all the requisite information, and no duplicative work, is provided with the CPCN application. Utility responsiveness and cooperation is critical to the success of these staff efforts. Finally, the CPUC is investigating new technologies that might reduce the environmental impact of necessary transmission infrastructure, thereby reducing public opposition and the risk of delay.

- Successful application of these reforms is illustrated in the reduction in the time assumed for CEQA/ National Environmental Policy Act (NEPA) review from 24 months in Timeline 1 to 18 months in Timelines 2A and 2B.

Need Determination

In addition to CEQA review, the CPUC has a statutory obligation to examine the "need" for any proposed transmission line, and during the CPCN application process the CPUC has carried out this "need determination" in parallel with its CEQA review. Typically, the California ISO has made a finding of need before a project reaches the CPUC under its Federal Energy Regulatory Commission-approved tariff and North American Electric Reliability Council/WECC reliability standards. This evaluation considers reliability, economic, and operational benefits of proposed transmission upgrades to California ISO ratepayers. This analysis is conducted in the California ISO's Transmission Planning Process.

In a 2006 decision, the CPUC adopted a procedure by which the CPCN process could be streamlined by granting, under certain circumstances, a presumption of reasonableness to the California ISO's need determination. The CPUC and California ISO are currently working together to refine and streamline this procedure and the overall permitting process by improving the coordination of their respective transmission review and approval processes in a number of ways, including alignment of the alternatives that are considered in the California ISO's economic and the CPUC's environmental analyses. The improvements under consideration will expedite the "need determination" required for transmission applications by coordinating the processes of the CPUC and the California ISO to reduce gaps and redundancies in the current process. Such coordination aims to reduce the amount of time involved in determining the need for a transmission line, reduce the risk of legal challenges of that determination, and reduce the amount of time involved in planning the lines and preparing CPCN applications.

- Successful coordination on "need determination" is reflected in Timelines 2A and 2B by the overlap between application development, environmental review, and transmission planning – resulting in savings of 12-18 months – and by the reduction of "final approval" from 4-5 months to 3 months. This coordination could also prevent additional delays due to legal challenges of need determinations.

Reform 3: Streamlining Generation Permitting

The Energy Commission and other state and federal agencies involved in permitting and siting renewable generation projects have taken several steps that may help to streamline their review of renewable generation facilities. In August 2007, the Energy Commission and the BLM signed a memorandum of understanding in order to conduct a joint environmental review of renewable projects that fall under both of their jurisdictions. The BLM is also developing a programmatic environmental impact statement for solar facilities, and the Governor's Executive Order S-14-08 directs the Energy Commission and the Department of Fish and Game to conduct programmatic environmental review of renewable generation in the Colorado and Mojave Deserts. This work will help to identify areas in the desert where renewable generation might cause the least environmental harm, and would help to facilitate the permitting of solar facilities in those areas.

The work will also consider the impact of transmission necessary to deliver those renewable resources to load, and may help to streamline the environmental review of those transmission lines. While this reform is very important, it does not improve existing resource and staff constraints at these agencies, which must be addressed if streamlining of the generation permitting process is going to be successful. See Table 11 for a summary of the number of renewable generation projects each agency would need to process under the 33% RPS Reference Case.

- While Timelines 2A and 2B do not change the 30 month transmission-generation time lag assumption, they do account for generation streamlining by assuming no increase in processing time, even given the magnitude of new projects that would require generation permits at approximately the same time.

Reform 4: The Renewable Energy Transmission Initiative

RETI will help reduce the amount of time needed to develop plans of service for transmission lines. Specifically, RETI stakeholders are developing conceptual transmission lines and prioritizing line segments that the California ISO will review immediately under its detailed planning process in 2009-2010. RETI's efforts to involve a broad range of stakeholders at the federal, state, and local levels early in the planning process may also mitigate delays later in the process, especially in the CPCN approval process.

- RETI's efforts are reflected in the assumption in Timeline 2A and 2B that two new transmission projects enter the development process in 2010, rather than the one new project per year assumed in Timeline 1.

Reform 5: California ISO Planning for Renewable Resources in 2010 Transmission Planning Process

In the third quarter of 2009, the California ISO plans to issue a conceptual transmission plan based on the results of Phases 1 and 2 of RETI. This study, which will be informed by the first results from the GIPR study process, will be a conceptual master plan for achieving a 33% RPS by 2020 and will allow the California ISO to efficiently design a reliable transmission system for California and the WECC. This plan will go before the California ISO Board in the first quarter of 2010, along with the California ISO's 2010 Transmission Plan.

During 2010, the California ISO will begin the Large Project stakeholder study processes for the highest priority components of its conceptual master plan, followed by further projects in subsequent years. In order to ensure the development of a reliable transmission system, built in a least-cost manner, the California ISO has indicated that the planning for the transmission needed for a 33% RPS must be staged through at least 2014. The order in which projects enter the stakeholder study process is a critical question that will be informed in coming months and years by RETI, GIPR, the Long-Term Procurement Plans, and other processes, largely in the context of the California ISO's Annual Transmission Planning Process.

- The California ISO's plans are reflected in the addition of the "conceptual master plan" to Timelines 2A and 2B, and the staged planning of individual renewable transmission projects through the first quarter of 2015.

Implication: Transmission planning is a time-intensive process, and the California ISO's estimation of the time required to plan transmission for a 33% RPS is a key driver of the Timeline 2A and 2B results. Thus, successful execution of the California ISO's plan – beginning with the study planned for completion in September 2009 – is crucial.

Reform 6: Transmission Corridor Designation

The federal government and the state have recently enacted legislation to require designation of transmission corridors. Designation of such corridors can help streamline environmental review of transmission facilities proposed within those corridors, and can minimize stakeholder concerns, provided that stakeholders were fully engaged in the designation process. The federal government has identified numerous corridors in California, and the CPUC anticipates that these corridor designations will be extremely valuable in permitting new transmission facilities. The legislature has also directed the Energy Commission to identify transmission corridors in California, and the Energy Commission may initiate corridor designation for some of the paths that RETI identifies as valuable in the longer-term. *Once corridors are identified, an important next step is to secure the ability to use those corridors, perhaps through the purchase of high-priority corridors.*

- Corridor designations contribute to the reduction of the CEQA/NEPA review time from 24 months in Timeline 1, to 18 months in Timelines 2A and 2B.

ILLUSTRATIVE TIMELINE 2B: CURRENT PRACTICE WITH PROCESS REFORM AND EXTERNAL RISKS

As noted, Timeline 2A is not a realistic timeline, since it assumes no external development risks cause delay to generation or transmission projects. Experience indicates that large infrastructure projects can be delayed for many reasons. In the case of renewable energy infrastructure, many of these risks, such as technology, financing, and permitting risk, can be identified, but not necessarily predicted. See the text after Figure 9 for more discussion of these external risks.

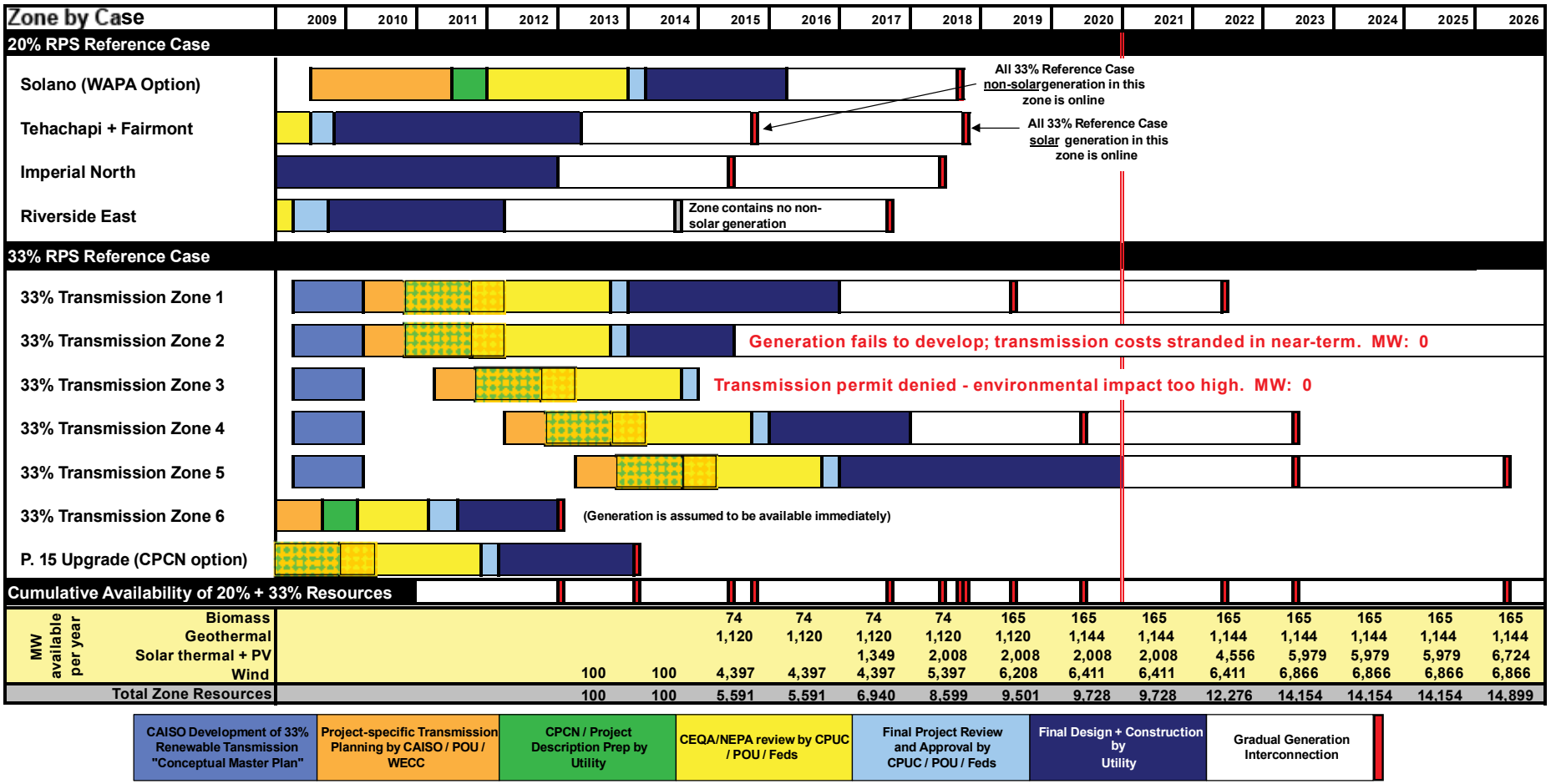
In Timeline 2B, "current practice with process reform and external risks," (Figure 9) the state encounters numerous project development delays that undermine the reforms identified in Timeline 2A. As a result, the 33% RPS Reference Case is not achieved. *The specific time delays shown in Timeline 2B, and the zones to which those delays are assigned, represent one possible scenario, given the risks that are known today*. There are several specific reasons that achievement of the 33% RPS is hindered in Timeline 2B:

- All timelines and reforms in Timeline 2A are assumed in Timeline 2B, but negative outcomes to several external risks now facing the state are realized. Timeline 2B maintains the assumption from Timeline 2A that there are no resource constraints in processing transmission and generation permitting applications.
- Generation in one zone fails to develop, resulting in new transmission capacity that goes unused in the near-term (stranded costs).
- Transmission to one zone is denied its permit because of environmental concerns or other opposition.
- Construction of the last transmission project is delayed by two years due to workforce and human resource constraints or the inability to finance the project.
- Solar projects throughout California take three years longer to develop than previously anticipated due to financing difficulties, performance failure, permitting difficulties, or other factors.[39]
- The outcomes above, and their implications for the 33% RPS time horizon, are not fully realized until 2014 and later. New generation and transmission development would likely begin to replace the failures/major delays, but 2014 may likely be too late to change course for a 2020 deadline. This analysis did not consider the addition of "replacement zones" to the 33% RPS Reference Case or procurement strategies not dependent on new transmission.

Implication: California's current procurement path is focused almost solely on central station renewable generation that is dependent on new transmission. In order to mitigate the risk that one resource zone would fail to develop, delaying the achievement of a 33% RPS by several years, the state should implement a procurement strategy that adequately considers the time and risk, in addition to price, associated with particular renewable generation resources. The state may also wish to adopt risk mitigation strategies, such as planning for more transmission than needed to reach just 33%, pursuing procurement that is not dependent on new transmission, or other solutions.

[39] This assumption is not particularly pessimistic, given the large number of solar thermal projects in the 33% RPS Reference Case relative to capacity installed worldwide to date (see Figure 14). Timeline 2B still assumes the interconnection of nearly 5,000 MW of solar thermal resources over the course of about 6 years.

Figure 9. Illustrative Timeline 2B for the 33% RPS Reference Case: Current Practice With Process Reform and External Risks



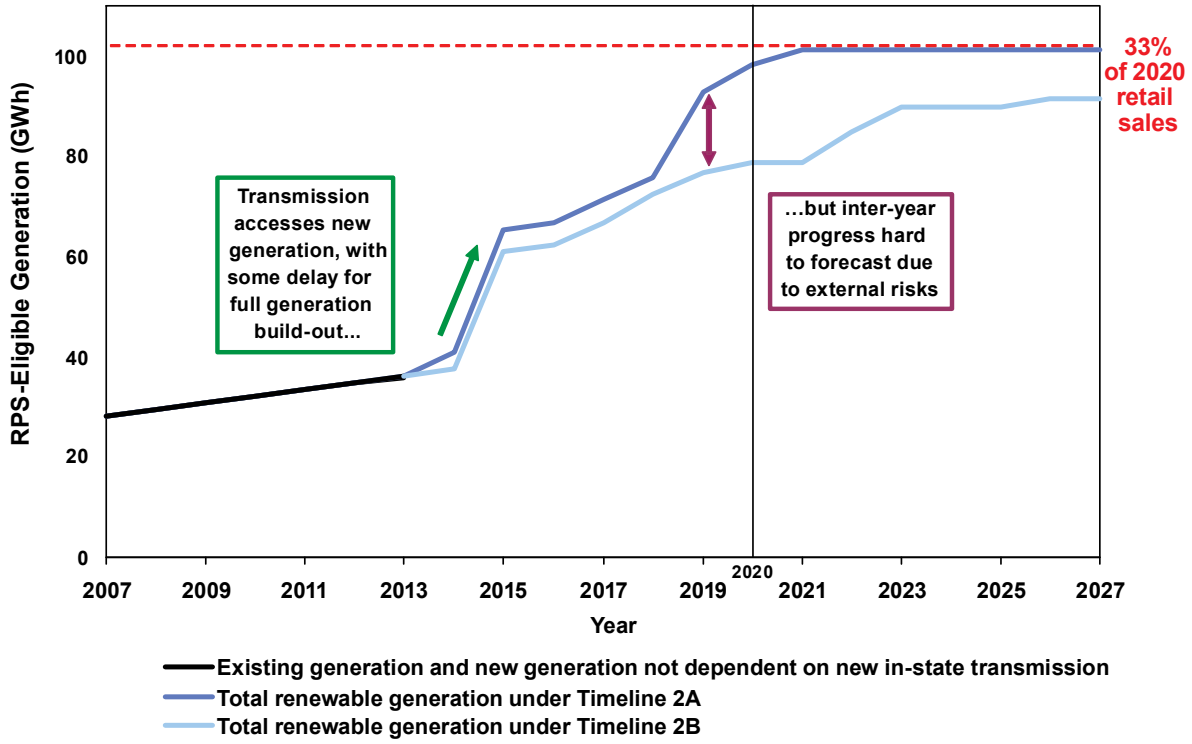
Source: CPUC/Aspen

Result: The 33% RPS Reference Case is not achieved due to unexpected problems with the development of two zones and delays in deployment of large-scale solar projects. Regardless of the nature of the risks that may actually occur, realization of any risk could cause delay and have a significant impact on timing. Although the state does not have direct control over many of the risks facing renewable energy development, it could adopt strategies that would mitigate specific risks.

ANNUAL RENEWABLE GENERATION BUILDOUT

The uncertainty around the external risks that are modeled in Timeline 2B makes it difficult to predict the renewable buildout on a year-to-year basis. Figure 10 illustrates the difference in the year-to-year progress achieved in Timelines 2A and 2B. This figure shows that administrative reforms speed up the renewable resource buildout, but inter-year progress is difficult to forecast due to external risks.

Figure 10. Annual Renewable Generation Buildout for Timelines 2A and 2B



Source: CPUC/E3

Implication: 33% RPS legislation should provide flexibility around annual targets or compliance rules due to the uncertainty around the renewable resource buildout year-to-year.

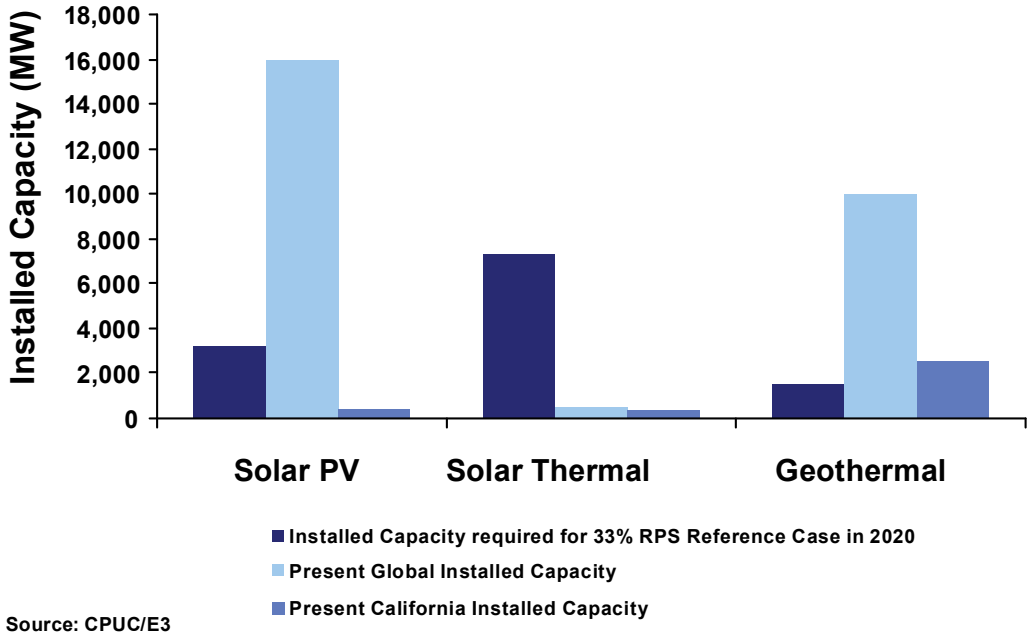
EXTERNAL RISKS THAT COULD DELAY 33% RPS RENEWABLE BUILDOUT

Below, some of the external risks that affect renewable energy development are described in more detail. These risks are outside the direct control of state agencies, and are included in Timeline 2B.

Reliance on New Technologies and Companies

Solar thermal and large-scale solar PV are promising technologies that show significant potential for providing reliable renewable power at competitive prices over the long-term. Solar technology participation in California's renewable energy solicitations has sharply increased in recent years, and the state's utilities are signing and negotiating thousands of megawatts of contracts for utility-scale solar power. The 33% RPS Reference Case includes over 7,000 MW of proposed solar thermal projects and over 3,000 MW of proposed solar PV. These new and emerging technologies, however, face some of the highest risks in terms of project viability. Unlike on-shore wind energy, and to a lesser degree geothermal energy, some solar thermal and solar PV technologies are not yet deployed widely on a utility-scale. Figure 11 shows the global installed capacity of solar PV, solar thermal, and geothermal resources as of 2008 to the right of the quantity of resources required to meet the 33% RPS Reference Case.

Figure 11. Global and Statewide Installed Capacity Versus Installed Capacity of 33% RPS Reference Case in 2020[40]



Source: CPUC/E3

[40] Wind is excluded from this chart to maintain scale. There was more than 121,000 MW of worldwide global installed wind capacity in 2006, compared to about 10,000 MW assumed in California in 2020 in the 33% RPS Implementation Analysis. Global Installed capacity numbers are from the "Renewables Global Status Report 2009." The California installed capacity for solar PV and solar thermal are from the Energy Commission's Energy Almanac. The installed capacity for geothermal is from the Geothermal Energy Association's website. All numbers are through 2008.

As indicated in Figure 11, there is currently only about 500 MW of solar thermal capacity installed worldwide. The 7,000 MW of solar thermal included in the 33% RPS Reference Case would represent a 14-fold increase in global installed capacity. Both solar PV and geothermal technologies have been installed around the world in quantities exceeding those required to meet the 33% RPS target in California by 2020. However, the 33% RPS Reference Case would require increasing worldwide installed solar PV and geothermal capacity by about 15%, relative to 2008 levels. Likewise, the High DG Case includes about 15,000 MW of solar PV; this represents nearly a doubling of global solar PV capacity in California over the next 10 years, which is in addition to strong solar PV demand in other countries.

Reliance on technologies untested at this scale is risky. The primary risk is that relatively new solar thermal technologies will not be able to operate at utility-scale. Furthermore, assuming that each new technology ultimately does reach commercialization, there is still substantial risk that unanticipated technical hurdles will delay projects and prevent the necessary solar resources from coming online by 2020. A variation of this scenario is reflected in Timeline 2B: solar resources are assumed to require five years longer to develop than anticipated in Timeline 1. It should also be noted that technological breakthroughs for renewables could occur, but past experience indicates that these breakthroughs would need to occur nearly immediately in order to influence a 2020 timeline.

In addition to technology risk, many renewable energy technologies are evolving rapidly and the changing nature of the renewable energy sector means that clear market leaders have not emerged from among the many renewable energy developers. Over the next several years, it is likely that a number of these companies will fail as companies with superior technologies or better access to capital gain market share. This level of uncertainty in the market represents both a risk and an opportunity for California. It is a risk because not all of the state's renewable energy contracts are likely to result in commercially operational projects by 2020. On the other hand, it is an opportunity, since California's investment in renewable energy today is likely to further development of the renewable energy market overall. This highlights the tension between meeting the 33% RPS goal by 2020 and furthering long-term market transformation. If California values long-term market transformation, then a strategy that relies heavily on emerging technologies could accomplish that goal. However, this strategy will be less likely to achieve the 2020 target than a strategy that relies only on mature technologies.

Implication: California's high reliance on relatively new technologies and companies risks achievement of the 33% RPS in 2020. A planning process that allows balancing of time, risk, and cost associated with renewable development should provide opportunities for emerging technologies to demonstrate commercialization at projected costs without compromising stated policy goals.

Generation and Transmission Financing

Table 13 shows the estimated amount of capital investment required to construct all of the facilities selected in the 20% and 33% RPS Reference Cases. This figure includes the costs of new transmission lines as well as new renewable and conventional generating facilities needed to meet the RPS target and serve load reliably. Building the generation and infrastructure necessary to reach the 20% RPS Reference Case requires almost $52 billion of capital, while achievement of the 33% RPS Reference Case is estimated to require more than twice as much, approximately $115 billion. These numbers do not reflect the net costs to the ratepayers, but rather the amount of investment capital that will be needed to finance a 20% or 33% RPS.

Table 13. Cumulative Statewide Capital Investment Required Through 2020 Under the 20% and 33% RPS Reference Cases (billions of 2008 dollars)

	20% RPS Reference Case	33% RPS Reference Case
New Renewable Generation	$32.8	$95.3
New Transmission	$4.0	$12.3
New Conventional Generation	$15.0	$6.9
Total Capital Investment Required	***$51.8***	***$114.5***

In light of the magnitude of the capital investment required to achieve the state's RPS goals and serve load reliably, the current economic downturn poses another risk to the achievement of the state's 33% RPS goal by 2020. As credit availability has tightened in 2009, some companies are finding it harder to raise the capital they need to develop renewable generation and transmission projects. In addition, many of the newer renewable technology companies are still actively seeking venture capital, which is less plentiful than in recent years.

Some of the financing challenges may be mitigated in the short term by the American Recovery and Reinvestment Act (ARRA) of 2009 that President Obama signed into law on February 17, 2009. However, it is unclear to what extent ARRA is a solution given that these projects must begin construction in the next two years if they are to benefit from these new federal provisions. Moreover, tightened credit requirements are likely to be a long-lasting legacy of the current financial crisis, which may make it more difficult and expensive for renewable project developers to obtain financing for projects needed to achieve a 33% RPS by 2020.

Implication: Achieving a 33% RPS by 2020 is projected to require almost $115 billion of total investment, which is more than double the estimated $52 billion investment needed to reach the 20% RPS. If investors are going to provide the capital, they will need to have a high degree of confidence in specific renewable projects, in the ability of the California ISO and utilities to construct the needed transmission to integrate the renewable resources into the California grid, and in the willingness of policymakers to allow utilities to recover the costs from ratepayers.

Environmental Impacts

New renewable projects and transmission lines may create a range of significant and long-lasting environmental impacts. Many impacts may be reduced through engineering, design, and the use of careful construction practices. Other impacts are likely to remain significant and potentially unavoidable. Specifically, renewable projects using wind and solar technologies involve especially large areas: a single solar project can cover as much as 10,000 acres of land, about one-third of the total land area of San Francisco, completely converting the land to energy production.

Environmental impact analyses for new large renewable generation projects are now under way. The Energy Commission and BLM are reviewing applications for solar projects using different solar thermal technologies and local agencies are reviewing projects of large-scale wind and solar PV technologies. The completed analyses demonstrate that these projects have the potential to create a range of significant and long-lasting environmental impacts.

Some of the environmental impacts that can result from large renewable generation facilities, which are now being studied in an attempt to develop appropriate mitigation, are the following:

- A permanent loss of habitat for protected wildlife species and special status plants would occur. The availability of adequate mitigation land to compensate is uncertain, especially for expansive solar projects.
- Large projects would create blockage of wildlife corridors, potentially constraining or eliminating important linkages between sensitive population groups.
- Birds and bats can collide with wind turbines if located in areas with notable or threatened avian populations.
- A permanent change in the visual character of open spaces or agricultural areas would occur, inserting large expanses of industrial features to previously uninterrupted vistas. Desert views would also be affected by glare from the mirrors and towers used in some solar thermal technologies. Wind turbines would alter hilltop and ridgeline views.
- Limited supplies of groundwater would be used for regular cleaning of thousands of mirrors and panels for solar installations.
- Public lands in the desert would be converted from open space, available for multiple uses such as recreation, mining, and grazing, to a single exclusive purpose – power generation.
- A cumulative loss of resources would occur as the impacts above are realized throughout California – especially in the desert, where over 100 projects are already proposed.

Implication: Environmental permitting agencies will face difficult choices in the years ahead, as they struggle to balance environmental conservation and renewable and GHG emission reduction goals. Such choices, made in the context of permit applications for individual generation and transmission projects, will greatly affect the date by which the state can achieve a 33% RPS.

Legal challenges and public acceptance of environmental impact

Permitting agencies must weigh carefully the environmental and economic benefits associated with proposed renewable generation projects and transmission lines, against the environmental harm done by such extensive infrastructure development. The process of approving generation and transmission projects can be delayed as a result of public opposition or associated legal challenges. While no transmission line approval granted by the CPUC has been successfully challenged in court in the past 15 years, most projects are met with increasing amounts of public opposition. New transmission lines needed to deliver remote renewable resources would likely range in length from 20 to 200 miles, and large-scale renewable development in desert areas would also require transmission upgrades within most of the coastal metropolitan areas to deliver the energy to loads. Transmission lines in these areas face property and right-of-way constraints and have traditionally faced substantial public opposition.

Public opposition to local, Energy Commission, and BLM approvals of large renewable generation projects also appears to be increasing. The public and various interest groups have raised particular concerns about the scale and magnitude of large-scale solar projects in the desert. Projects currently proposed in the Southern California desert would each cover 3,000 to 10,000 acres depending on technology and generation capacity, and over 70 of these projects have filed applications with the BLM on nearly 700,000 acres. While not all of these projects will ultimately be needed or constructed, the 33% RPS Reference Case would include construction of roughly 30 large solar projects in the Southern California desert, which could result in the environmental impacts described above. Valid concerns about such impacts, as well as NIMBY (Not In My Back Yard) concerns, may be raised in the permitting process and lead to delay or even denial of permits.

Implication: Public opposition to large-scale renewable energy infrastructure could delay or halt progress towards a 33% RPS. RETI works to reduce opposition by involving stakeholders early in the development process, but the state may also consider other options for reducing the risk of public opposition, including different procurement strategies or concentrated renewable development in one or more renewable energy parks. Tradeoffs in terms of resource quality and price may be warranted if it appears that development in more cost-effective areas faces too great a risk of delay.

5 Summary of 33% RPS Cases

This section shows how the 33% RPS cases perform against the various policy goals and objectives of a 33% RPS, based on the results described in Sections 3 and 4. Through a number of executive orders and state law, state policymakers have articulated numerous policy goals and objectives for achieving a 33% RPS, which are outlined in Section 1. In this section, quantitative and qualitative analysis of the performance of alternative strategies is presented for meeting a 33% RPS in addressing state policy goals and objectives. Table 14 depicts these findings.

CASE OVERVIEW

Commonalities among all the cases:

All of the 33% RPS cases result in GHG emission reductions similar to those established by the ARB in its Scoping Memo. As mentioned previously, GHG emission reductions are measured based on the emissions reduced during generation. A lifecycle GHG analysis was beyond the scope of this analysis. The 33% RPS cases also perform equally well in reducing reliance on fossil fuels and increasing resource diversity. As demonstrated through the natural gas and CO_2 allowance price sensitivity analysis, all of the 33% RPS cases provide a hedge against fluctuating natural gas prices, but at a relatively high cost.

Differences among the cases:

Each of the 33% RPS cases has a different impact on ratepayers. While a detailed implementation analysis was not conducted on any of these alternative strategies, the timing does seem to differ across the cases since different technologies have different construction durations and transmission needs. As for development risk, different technologies face different risks, depending on whether the technology is emerging or commercially proven.

The cases may differ in terms of economic impacts as well. All cases result in higher electric rates, reducing disposable income for California consumers. However, renewable infrastructure construction, operations, and maintenance result in some local job creation, depending on how much of the infrastructure is located in California. Regardless of where the project is located, economic benefits could accrue to California if renewable companies establish their operations in California. Lastly, local environmental quality differs across the cases since different technologies have different land and air quality impacts.

33% RPS Reference Case (current IOU procurement strategy)

- *Cost Impact:* 7.1% cost premium compared to the 20% RPS Reference Case. Most expensive case relative to other alternative 33% RPS cases except for the High DG Case.
- *Economic Development:* More in-state jobs compared to the High Out-of-State Delivered Case.
- *Local Environmental Quality:* High reliance on large-scale solar technologies could decrease local environmental quality due to land impacts, but high reliance on in-state generation could displace existing fossil fuel generation and reduce local air and water pollution.
- *Timing:* High reliance on central station renewable resources, which require new transmission, suggests a higher likelihood of delays.
- *Development Risk***:** Many external risks, such as reliance on new, unproven technologies could delay the 2020 target beyond the transmission delays.
- *Long-Term Market Transformation:* Reliance on new solar technologies could lead to future cost-reductions and technology breakthroughs.
- *Conclusion:* This case is most likely to miss the 2020 target timeline due to the amount of significant transmission required and its heavy reliance on new, unproven technologies. This case does excel in long-term market transformation.

High-Wind Case

- *Cost Impact*: 4.1% cost premium compared to the 20% RPS Reference Case.
- *Economic Development*: Case results in similar in-state job creation to 33% RPS Reference Case, and lower rates means higher disposable personal income.
- *Local Environmental Quality:* Wind technologies have both positive and negative effects. Wind has a smaller land footprint compared to solar, but can lead to bird mortality. In addition, wind technologies could require a greater amount of fossil generation to backup the generation during non-peak hours, which could decrease local air quality.
- *Timing:* Wind technologies have a shorter development period compared to other renewable technologies, which could facilitate achievement of a 33% RPS by 2020. On the other hand, wind technologies also need new transmission.
- *Development risk:* Less of a concern for wind since the technology is mature.
- *Long-Term Market Transformation:* Wind technologies contribute less to long-term market transformation since the technology is mature.
- *Conclusion:* This is a cost effective way of achieving a 33% RPS, but is likely to miss the 2020 timeline because of the amount of transmission required. While it performs reasonably well with the other policy categories, it does not excel in any of them.

High Out-of-State Delivered Case

- *Cost Impact:* 3.8% cost premium compared to the 20% RPS Reference Case.
- *Economic Development:* This case creates fewer in-state jobs compared to the 33% RPS Reference Case due to a higher reliance on out-of-state resources; however, lower rates mean higher disposable personal income.
- *Local Environmental Quality:* Greater reliance on out-of state resources could preserve sensitive lands in California, but out-of-state resources may not help improve local air quality since local fossil resources may still have to run for resource adequacy purposes.
- *Timing:* Out-of-state resources may have shorter development timelines since much of the out-of-state development is focused on wind, but a high reliance on new, multi-state transmission line development adds risk.
- *Development risk:* Less of a concern for out-of-state resources since wind and geothermal are mature technologies.
- *Long-Term Market Transformation:* Wind and geothermal technologies contribute less to long-term market transformation since the technologies are mature.
- *Conclusion:* Of the cases studied, this case provides the lowest cost strategy to achieve a 33% RPS, although the cost is not much less than the High Wind Case. High reliance on multi-state transmission introduces an element of risk into the 2020 timeline. This risk could be mitigated through tradable RECs with no delivery requirement, which would also lower the cost of out-of-state resources. This case does not perform well on the other policy preferences.

High Distributed Generation Case

- *Cost Impact:* 14.6% cost premium compared to the 20% RPS Reference Case. This cost is substantially higher than the 33% RPS Reference Case and alternative 33% RPS cases since this case relies on distributed generation, primarily solar PV, to fill the 33% RPS resource needs.
- *Economic Development:* Could create more jobs than the other cases since rooftop PV is labor intensive; however, California electricity expenditures would be nearly $4 billion higher than the 33% RPS Reference Case, which would lead to lower economic development and job growth for other businesses overall.
- *Local Environmental Quality*: Performs well since case minimizes transmission and maximizes rooftop installations. It can also improve local air quality by displacing in-state local fossil generation.
- *Timing:* Could perform well on timing and could assist meeting the 33% RPS in 2020, though transaction costs and potential supply constraints to meet the high number of installations make timing uncertain.

- *Development risk:* Such large amounts of solar PV on the distribution grid could create grid reliability problems, which could slow development. In addition, this strategy would require nearly a doubling of global solar PV capacity, which could lead to supply chain constraints, affecting the timing.
- *Long-Term Market Transformation:* Case could benefit medium-term market transformation of the solar PV market and lead to future cost-reductions.
- *Conclusion:* A high DG strategy could facilitate achieving a 33% RPS in 2020 as well as mitigate some of the need for transmission and transform the market for solar PV technologies. However, less is known about the feasibility of this case, including the willingness of building owners to rent their rooftops, impacts on grid reliability, effectiveness of utility programs and other delivery channels, and whether both manufacturing capacity and a trained workforce will be available to meet this large increase in demand. This case has the highest cost unless there are significant cost breakthroughs in solar PV technologies.

Table 14. Comparison of 33% RPS Cases Across RPS Policy Objectives[41]

Policy Objective	33% RPS Reference Case	High Wind Case	High Out-of-State Delivered Case	High-DG Case
Cost	◒	●	●	○
Timing	○	◒	◒	◒
GHG Emission Reductions	●	●	●	●
Resource Diversity	●	●	●	●
Local Environmental Quality Air Quality	●	◒	○	●
Local Environmental Quality Land Use	○	◒	◒	●
Economic Development	◒	◒	○	◒
Long-Term Transformation	●	○	○	●
Technology Development Risk	○	●	●	○

Legend:

● Case performs well ○ Case performs poorly ◒ Case is neutral

[41] This study only preformed an implementation analysis on the 33% RPS Reference Case. Thus, evaluation of other cases for all criteria (except for cost and GHG reductions) is based on a qualitative analysis drawing from over seven years of experience in implementing the RPS program.

6 Findings

The purpose of this report is to provide new and in-depth analysis on the cost, timing, and risks of a 33% RPS for the State of California. This report does not recommend a preferred strategy on how to reach a 33% RPS, but rather provides an analytical framework for policymakers to understand the tradeoffs inherent in any 33% RPS program for California. The analysis also highlights the need to prioritize different policy objectives as well as the need to start considering mitigation strategies to lesson the effects of delay from external risks.

KEY FINDINGS OF THIS REPORT

Achieving a 33% RPS will require tradeoffs between various policy goals and objectives

There are multiple strategies the state could pursue to reach a 33% RPS, but each portfolio will have different cost impacts, reach the 33% RPS target at a different date, and perform differently across the broad list of stated policy goals and objectives. For example, the results of this analysis show a relationship between timing and the maturity of various technologies. Specifically, using proven technologies increases the chances of reaching the target date of 2020, while relying on new technologies decreases the chances of making the target date. This relationship is evident in the current procurement strategies that the California IOUs are pursuing. The IOUs are currently signing multiple contracts with solar thermal projects, which reflects risks inherent to the emerging nature of the technology, including higher prices and performance risk. While this strategy has the potential for long-term market transformation, it risks high costs and failure to meet the 33% RPS in 2020.

Table 15 provides four examples that illustrate how a specific policy priority results in different renewable procurement strategies. A "Least-Cost" policy priority, for example, demonstrates a preference for low-cost renewables, most likely from outside of California. The "2020 Timeline" policy priority focuses on achieving a 33% RPS by the fixed deadline of 2020, with a high reliance on commercialized technologies and high levels of DG, while "In-State Jobs" priority relies most heavily on procurement strategies that will lead to the most in-state job development. "Market Transformation" relies heavily on developing market transformational technologies such as solar thermal, but also contains the highest risk of missing the 2020 deadline. Each of these policy-driven procurement strategies also demonstrates the tradeoffs that would have to be made in terms of the other policy preferences and objectives.

Table 15. Sample Renewable Procurement Options Based on Policy Priorities

Least-Cost Renewables	2020 Timeline
Procurement Priority: 1. In-state development of lower-cost resources and commercialized technologies, such as wind and biomass.[42] 2. Least-cost renewable energy delivered to California, including construction of new interstate transmission lines. 3. Procurement of out-of-state renewable energy facilitated through tradable RECs with no delivery requirement. *Cost*: Lowest *Timing*: 2020 likely since the lower cost resources also have shorter development periods. Based on program experience, out-of-state resources can be built faster than in-state resources. *Market Transformation:* Low as there is heavy focus on existing technology.	*Procurement Priority:* 1. Near-term renewable energy projects in California, with focus on commercial technologies that do not need new transmission, such as DG. 2. Viable out-of-state resources delivered to California over existing transmission. 3. Procurement of out-of-state renewable energy facilitated through tradable RECs with no delivery requirement. *Cost*: Medium High *Timing*: 2020 likely because of high reliance on existing transmission, existing technologies, and high DG. *Market Transformation:* Medium low, since there is heavy focus on existing technology, although it could contribute to solar PV price reductions.
In-State Jobs[43]	**Market Transformation**
Procurement Priority: 1. High focus on in-state renewables including both high and low cost renewables and those that require new in-state transmission. *Cost*: Highest - higher rates could have unintended consequences and lead to job loss in other sectors. *Timing*: Post 2020 likely, but heavy focus on DG could help mitigate the time lag of potential transmission bottlenecks and potential permitting issues. *Market Transformation:* Medium high if there is a mixture of new and existing technologies.	*Procurement Priority:* 1. Emphasis on emerging, likely higher-cost renewables, such as solar thermal, with significant transformational benefits. *Cost*: Medium High *Timing*: Post 2020, highest risk due to technology uncertainty. *Market Transformation:* Highest due to significant investment in new technologies.

These priority portfolios show that a low-cost strategy may be able to achieve a 33% RPS by 2020 using commercial technologies and out-of-state resources. However, a strategy that prioritizes mostly in-state development or market transformation will cost more and take more time to achieve. Given the large number of contracted solar thermal resources and current

[42] These numbers do not include a full study of renewable integration costs. As a result, the relative cost of this strategy could change once Phase 3 is complete, including California ISO analytical input.
[43] Only accounts for jobs directly resulting from RPS.

emphasis on in-state development, the 33% RPS Reference Case more closely reflects the "In-State Jobs" and "Market Transformation" procurement options described in Table 15. It is important to note that the IOUs are procuring at a very aggressive rate and it is expected that they will be at or close to a 33% RPS on a contract basis in the near future. As a result, the state may be already beyond the point where a purely "least-cost" strategy could be adopted.

California must start implementing mitigation strategies if a 33% RPS by 2020 is the most important policy priority

Timeline 2B provides an example of a scenario in which, despite successful implementation of ambitious reforms, two resource zones fail to develop due to external risks. While Timeline 2B presents a hypothetical example, it illustrates the potential impact of real risks that California's current procurement strategy is not prepared to mitigate. Specifically, California's current procurement path is focused almost solely on central station renewable generation that is dependent on new transmission. In order to mitigate the risk that one resource zone would fail to develop, delaying the achievement of a 33% RPS by several years, the state should consider a procurement strategy that adequately considers the time and risk, in addition to price, associated with particular renewable generation resources. The state may also wish to adopt risk mitigation strategies, such as planning for more transmission and generation than needed to reach just 33%; pursuing procurement, such as distributed solar photovoltaics (PV), which is not dependent on new transmission; or concentrating renewable development in pre-permitted land that would be set aside for a renewable energy park.

OTHER FINDINGS

The magnitude of a 33% RPS is unprecedented and will require nearly a tripling of renewable electricity in the next 10 years

To meet the current 20% RPS by 2010 target, four major new transmission lines are needed at a cost of $4 billion. To meet a 33% RPS by 2020 target, seven additional lines at a cost of $12 billion would be required. The 33% RPS target is projected to require an increase from 27 terawatt hours (TWh) of delivered renewable energy today to approximately 75 TWh in 2020.

Electricity costs will be higher in 2020 compared to 2008, regardless of whether California mandates a 33% RPS or not

Even if California makes no further investments in renewable energy, the analysis projects that average electricity rates per kilowatt-hour will rise by 16.7% in 2020 compared to 2008. In 2020, the total statewide electricity expenditures of the 20% RPS Reference Case is projected to be 2.8% higher compared to the all-gas scenario. The total statewide electricity expenditures of the 33% RPS Reference Case is projected to be 7.1% higher compared to the 20% Reference Case, and 10.2% higher compared to the all-gas scenario.

Several critical process reforms have been implemented or are in the early stages of development and implementation that can help speed achievement of a 33% RPS

These reforms will help increase the pace of renewable development. Even under very optimistic assumptions and after the process reforms have been implemented, the 33% RPS target by 2020 is highly ambitious. This is due to the risk from external factors and the magnitude of the infrastructure that California will have to develop, procure, and integrate in the next 10 years.

A 33% RPS could theoretically serve as a potential hedging strategy against volatile fossil fuel prices, but only if natural gas and CO_2 price allowances are very high

In theory, an increase in renewable penetration decreases the range of electricity expenditures by decreasing exposure to volatile fossil fuel prices. While a 33% RPS can provide this hedge, it only provides an effective hedge under very high natural gas and CO_2 prices. Thus, the "hedging value" from resource diversity is not a very strong justification for establishing a 33% RPS.

The interplay between energy efficiency achievement and renewable energy procurement highlights the need to analyze and plan for interactions among the state's various policy goals

Under a low-load scenario that could result from successful implementation of energy efficiency and other demand-side programs, the 20% Reference Case results in substantial capacity savings. On the other hand, the 33% RPS Reference Case results in less incremental capacity savings, which means that a 33% RPS will create capacity that is not needed to serve load, resulting in excess costs to consumers. This finding highlights the need to analyze interactions among the state's various GHG reduction programs. An integrated approach that considers both supply side and demand side programs is needed to ensure that the various programs result in a resource plan that furthers the underlying policy objectives of a comprehensive GHG reduction strategy.

Dramatic cost reductions in solar PV could make a solar DG strategy cost-competitive with central station renewable generation

Under the Solar PV Cost Reduction sensitivity, the total costs of the High DG Case are very similar to the costs of the 33% RPS Reference Case. The solar PV industry is predicting dramatic cost reductions in the coming years even though solar PV is currently the most expensive renewable technology studied in this report. Solar PV on the distribution system has numerous advantages, which include avoiding transmission and land use if sited on rooftops. However, even if solar PV technology costs drop dramatically, the deployment costs associated with thousands of megawatts of distributed PV could still be a challenge. In addition, capturing these megawatts could require a policy mechanism different from the RPS. More analysis is necessary to determine the programmatic strategies necessary to achieve a high-DG scenario as well as the feasibility of high penetrations of solar PV on the distribution grid.

RPS OBJECTIVES SHOULD BE PRIORITIZED

As this analysis has shown, many of the policy objectives are mutually exclusive and in conflict with one another. Currently, the RPS procurement process is effectively dictating the timing, cost, and policy objectives of a future 33% RPS program. Thus, the tradeoffs are being decided through the utility procurement process, not by the policymakers or regulators. Using current RPS contracts as an example, market transformation and in-state economic development are the primary policy objectives that are being prioritized at the expense of meeting a 2020 timeline and minimizing customer costs. This results from lack of having a stated priority preference. Some of the key questions to help determine a priority preference include:

- Should California focus public investment and system planning efforts on developing and integrating technologies with significant long-term transformational potential such as solar thermal or solar PV?
- Should California focus on developing in-state resources? Up to what cost? What is the correct balance between in-state economic development and higher customer costs?
- Is California willing to delay the 2020 target in order to develop primarily California resources and stimulate new technologies and market transformation?
- Should California waive renewable energy delivery requirements for out-of-state resources if it is necessary to meet the 2020 target or pursue a lower cost strategy?
- Should the CPUC encourage the utilities to procure increased amounts of (currently) high-cost solar PV to mitigate the potential negative impact of delay due to failure of a resource zone?

NEXT STEPS

This report captures the preliminary results and conclusions from Phase 1 and Phase 2 of the 33% RPS Implementation Analysis. Phase 3, which CPUC staff intends to finalize by the end of 2009, will integrate the California ISO's renewable integration analysis, RETI and the California ISO's conceptual transmission plans, and the Energy Commission's analysis of once-through cooling fossil plant retirements. In addition, CPUC staff will attempt to identify and articulate possible solutions to many of the risks and challenges identified throughout this report.

As stated previously, the study team did not perform an implementation analysis of the High Wind, High DG Case, or the High Out-of-State Delivered Case. Further analysis of the High Wind Case could help understand potential challenges to developing high levels of wind energy in California and other states. An implementation analysis of the High DG Case could help better understand the costs, reliability impacts, and barriers to implementing such large amounts of solar PV on the distribution grid. For the High Out-of-State Delivered Case, more analysis could help identify possible challenges to developing out-of-state resources and delivering them to California.

Lastly, given the findings from the low-load sensitivity, more analysis could help better understand the interplay between retiring fossil resources, achievement of the aggressive demand-side goals, and a 33% RPS.

Appendix A: List of Acronyms

Acronym	Definition
AB	Assembly Bill
AB 32	(California) Assembly Bill 32 – Global Warming Solutions Act of 2006
ARB	(California) Air Resources Board
ARRA	American Recovery and Reinvestment Act
Aspen	Aspen Environmental Group
BLM	Bureau of Land Management
California ISO	California Independent System Operator
CCGT	Combined Cycle Gas Turbine
CEQA	California Environmental Quality Act
CHP	Combined Heat and Power
CPCN	Certificate of Public Convenience and Necessity
CPUC	California Public Utilities Commission
CO_2	Carbon Dioxide
CREZ	Competitive Renewable Energy Zone
CSI	California Solar Initiative
DG	Distributed Generation
DR	Demand Response
EE	Energy Efficiency
ED	Energy Division
EIR	Environmental Impact Report
E3	Energy and Environmental Economics
FERC	Federal Energy Regulatory Commission
GHG	Greenhouse Gas
GIPR	Generation Interconnection Process Reform
GW	Gigawatt
GWh	Gigawatt-hour
IEPR	Integrated Energy Policy Report
IOU	(Large) Investor-Owned Utility
IRRP	Integration of Renewable Resources Program
ISO	(California) Independent System Operator
ITC	Investment Tax Credit
kWh	kilowatt-hour
LTPP	Long-Term Procurement Plans
MMBtu	Millions of British thermal units
$MMTCO_2E$	Millions of Metric Tons of Carbon Dioxide Equivalent
MPR	Market Price Referent
MW	Megawatt
MWh	Megawatt-hour
NEPA	National Environmental Policy Act
NIMBY	Not In My Backyard
PEA	Proponent's Environmental Assessment

Acronym	Definition
POU	Publicly-Owned Utility
PPA	Power Purchase Agreement
PTC	Production Tax Credit
PV	Photovoltaic
REC	Renewable Energy Credit
RETI	Renewable Energy Transmission Initiative
RFO	Request For Offer
RPS	Renewables Portfolio Standard
SB	Senate Bill
TWh	Terawatt-hour
W-e	Watt equivalent

Appendix B: Methodology

STUDY STRUCTURE

Study team and stakeholder process

The consultant study team was comprised of E3, Plexos Solutions (Plexos), and Aspen Environmental Group. Plexos conducted production simulation model runs to provide variable costs and GHG emissions. Although not part of the study team, Black and Veatch contributed to this effort by calculating the availability of rooftop space in urban areas as well as rural lands for siting solar PV projects, in addition to its contributions to the RETI work. CPUC Energy Division staff assisted the consultant team throughout the study period.

The 33% RPS Implementation Analysis Working Group and Transmission Constrained Working Group also contributed to this analysis. Energy Division formed these working groups after a 33% RPS workshop in August 2008. The working group members contributed significantly to this analysis through meetings, data submittals, written comments, and informal discussions. More specifically, the Implementation Analysis Working Group helped develop the 33% RPS Implementation Analysis Work Plan and the Transmission Constrained Working Group contributed to the development of the High DG Case. The working group met in December 2008 and January 2009 to review the study's initial analysis and preliminary results and provided valuable feedback and guidance to the study team.

Study Phases

This study has three phases, which are described below:

Phase 1: August 2008 – December 2008

In Phase 1, the study team utilized data from RETI and other data sources to compile the cost and location of renewable resources available throughout the West. The team also developed an environmental scoring method that built upon RETI's efforts. This information was used to develop resource zone rankings to select draft portfolios for each of the 20% and 33% RPS cases presented below. Stakeholders also provided comments on the 33% RPS cases developed during this phase.

Phase 2: December 2008 – May 2009

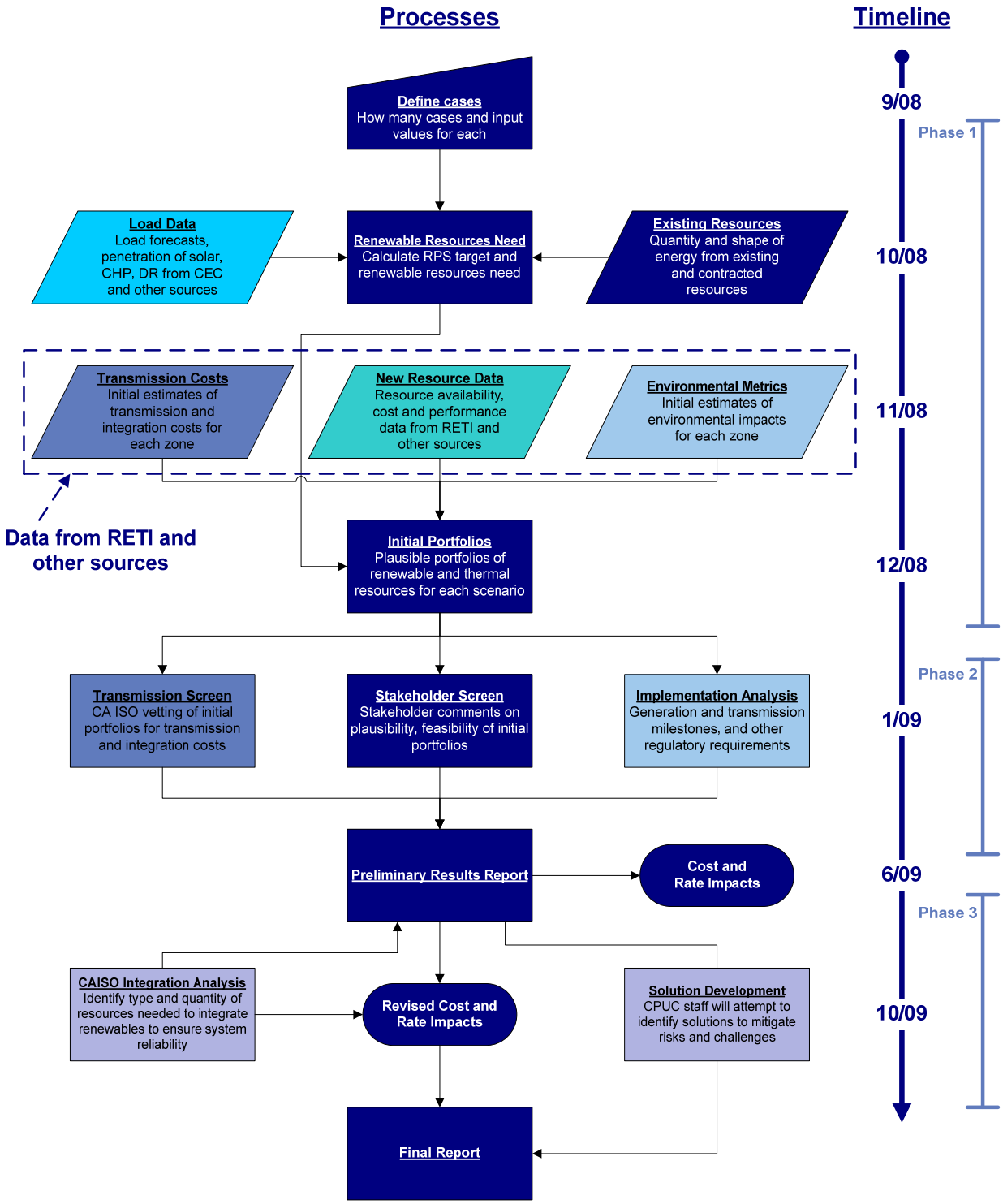
In this phase, the draft portfolios were refined based on stakeholder feedback. Production simulation model runs for the 20% and 33% RPS Reference Cases were conducted to determine the variable costs and GHG emission reductions, and the results were then used to assess the costs and GHG emissions for the alternative 33% RPS cases. The team also analyzed historical generation and transmission development and constructed timelines to illustrate the steps necessary to build new transmission and renewable energy projects in California. This report is the final deliverable of this phase.

Phase 3: April 2009 – Fourth Quarter 2009

The California ISO will identify the type and quantity of resources needed to reliably integrate the 33% RPS resource portfolios that were developed in Phase 2 of this study. Studies on once-through cooling retirements are expected to be completed in the next six months, which will also help inform the quantity and timing of new resources needed to integrate intermittent renewable resources. Based on these analyses, the study team will refine assumptions about the quantity and cost to integrate intermittent renewable resources into the grid.

In addition, RETI and the California ISO will finalize the conceptual transmission plans needed to reach a 33% RPS during the summer of 2009, which will identify the transmission buildout and cost needed to reach a 33% RPS. This will be incorporated into the analysis. Finally, CPUC staff will attempt to identify solutions to mitigate or overcome the risks and challenges identified in this analysis. The final deliverable of this study is the final report, currently scheduled for fourth quarter of 2009.

Figure 12. 33% RPS Implementation Analysis Study Flow Chart Depicting Phases 1-3



Source: CPUC/E3

METHODOLOGY TO CONSTRUCT RENEWABLE RESOURCE PORTFOLIOS

As described above, Phase 1 of this analysis focused on developing initial resource portfolios for each of the 20% and 33% RPS cases, which are composed of specific renewable projects. The study team assembled resource portfolios to meet a 33% RPS target and estimated cost impacts using the RPS Calculator. This section describes in more detail the methodology for constructing these renewable resource portfolios.

RPS Calculator

The RPS Calculator[44] is a Microsoft Excel spreadsheet model developed to aggregate the renewable cost and performance data and select renewable resources needed to meet the RPS target. The model also identifies transmission investments that deliver renewable resources to load and conventional resources that are needed to meet energy and peak demand growth, and calculates the cost and GHG impacts of a given portfolio of resources in 2020.

Renewable Resources Needed by 2020

The analysis starts with a statewide calculation of the renewable resources that California utilities must procure between 2008 and 2020 to meet a 33% RPS by 2020. The resources needed are calculated as the total required quantity of renewable energy in 2020 (33% of retail sales) minus the actual renewable generation that was claimed by California utilities in 2007.

To fill this renewable resource need, the study team gathered the best available data on renewable energy project development and renewable resource potential in California and throughout the West, and used the RPS Calculator to select portfolios of renewable resources.

Renewable Portfolio Data Sources

The analysis relied on four primary sources of data regarding renewable energy costs, resource potential, and commercial interest, each of which provided a level of granularity and accuracy that distinguishes this study from previous analyses. See Section 3 for a description of each data source.

1. CPUC Energy Division project database (ED Database) [45]
2. Renewable Energy Transmission Initiative[46]
3. The GHG Calculator[47]
4. Estimates of distributed renewable energy potential[48]

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[44] The RPS Calculator can be found on the CPUC RPS website: http://www.cpuc.ca.gov/renewables

[45] The CPUC maintains a public version of this database: http://www.cpuc.ca.gov/NR/rdonlyres/F07E249B-C36A-4A38-8D36-BDB88CDB154B/0/RPS_Project_Status_Table_1st_Quarter_2009.xls

[46] Renewable Energy Transmission Initiative: http://www.energy.ca.gov/reti/documents/index.html

[47] As part of its GHG modeling, E3 developed estimates of the cost and performance of renewable resources throughout the Western Interconnection based on data provided by NREL and Energy Information Administration. Detailed descriptions of the methodology can be found on E3's GHG modeling website: http://www.ethree.com/CPUC_GHG_Model.html

[48] Black and Veatch assisted this analysis by estimating large rooftop acreage in urban areas throughout California.

It should be noted that there may be some overlap and duplication of potential projects in the resource supply curves. In addition, renewable energy projects that came online in late 2007 and 2008 may not be represented in a few of the cases. Finally, while the analysis incorporates project information from IOU solicitations, it does not include information about new and projected municipal and cooperative utility renewable energy projects. These slight inaccuracies are insignificant enough that they should not affect the results of the cost and timeline analyses in any meaningful way.

Distributed Renewable Energy Potential

As mentioned above, this analysis includes original estimates of the technical potential to develop and interconnect renewable generation at the distribution level, which are included in all of the 33% RPS cases. Estimates in this study were based on a three screens: 1) the ability to 'easily' interconnect, 2) suitable sites, and 3) willing customers. The first screen was based on an analysis of peak load served by each distribution feeder on the IOUs' systems. Available interconnection capability was then allocated among multiple distributed resource types including solar PV, biogas, biomass, and CHP. The second screen was based on GIS[49] mapping conducted by Black and Veatch for RETI and for this analysis. The third screen is based on simple rules of thumb. In addition to the urban solar PV projects that one normally thinks of as "distributed," this study also included an estimate of 20 MW ground-mounted solar PV systems in rural areas based on the RETI assessment. Since few of these rural systems are expected to meet the 'easy' interconnection criteria, an increased cost of interconnection was incorporated.

Table 16. Screens and Criteria to Estimate Urban Solar PV Potential

Screen	Criteria
'Easy' Interconnection	Peak PV output < 30% of peak load at point of interconnection, and PV location within 3 miles of substation. Available capacity was allocated among distributed resource types.
Suitable Sites	In urban areas, available large roof area (greater than 0.5 acre flat roof) multiplied by 65% usable space. In rural areas, available land with low slopes near substations
Willing Customers	Participation assumed for 1/3 of the sites identified as "suitable sites" with 'easy' interconnection

Table 17 shows the statewide technical potential for each distributed resource used in the High DG Case.

[49] Geographic Information System

Table 17. High Level Distributed Renewable Technical Potential

Technology	Type	Capacity (MW)	Notes
PV	Large Roofs (> 0.5 acre)	3,810	Based on satellite imagery
PV	Small Roofs	2,224	One third of remaining 'easy' connection potential
PV	Ground Mounted	2,266	One third of remaining 'easy' connection potential
PV	Ground Mounted (> 30% of peak load at point of interconnection)	9,000	Exceeds the size for 'easy' connection and gets a cost penalty of $68/kW-year
Biogas	Distribution Connected	249	
Biomass	Distribution Connected	34	
Total		**17,583**	

Defining Renewable Resource Zones

A resource zone is an aggregation of renewable projects by geographic location, technology type and/or resource quality. The resource zones were adopted from RETI and the GHG Calculator are organized around clusters of projects in defined geographic locations. For these zones, this study assumes that a new transmission "trunk line" must be constructed in order to deliver the energy to load centers. Other "zones" may include projects that are not geographically connected, but which do not need transmission and share other similar characteristics that allowed them to be grouped together for computational simplicity. These include "distributed"[50] and out-of-state projects in the CPUC Database and the RETI database.

Determining Resource Portfolio Costs and Rankings

All costs are expressed in 2008 dollars, unless noted otherwise. With the exception of the Solar PV Cost Reduction Case, this study is confined to existing renewable technologies and assumed constant technology costs over the study period. This study did not attempt to predict breakthroughs in technological development or changes in capital or operational costs. In addition, high-level estimates of transmission costs and renewable integration costs were based on a literature review. The California ISO is developing a full network model of the 33% RPS Reference Case, which can be used to improve the transmission cost estimates. The California ISO will also provide an estimate of the resources needed to reliably integrate intermittent technologies. This information will be used to update the 33% RPS cost information in Phase 3 of this analysis.

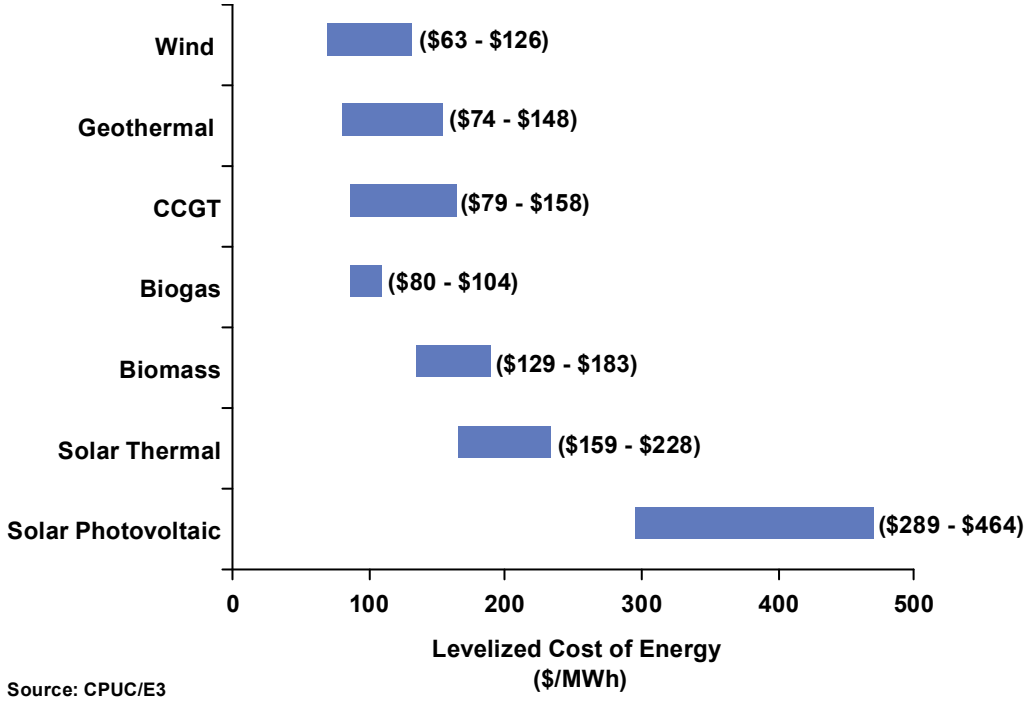
Estimates of the cost of constructing new renewable resources relied primarily on RETI data, which includes cost and performance information for hundreds of potential projects throughout

[50] In this context, "distributed" means simply projects that do not need large new transmission trunk lines in order to interconnect and deliver their energy to load.

California. This represents tens of thousands of megawatts of renewable development. The GHG Calculator contains characterizations of resources that RETI did not analyze, including biogas and small hydro. Based on these resource characterizations and assumptions about project finance, the RPS Calculator outputs a levelized cost of energy that represents the developer cost for each project used for project ranking. Figure 13 shows the resulting developer cost ranges ($/MWh) for each renewable technology considered in this analysis, along with a CCGT benchmark. The solar PV costs are for crystalline PV that is ground-mounted with single-axis tracking.

The project costs do not represent the negotiated contracted price. For most of the projects, the costs are the developer costs to build and operate the project with a reasonable profit. The exception to this assumption is renewable projects that cost less than the cost of a CCGT. These renewable projects were assumed to be at least as expensive as a CCGT since it is unlikely that developers will agree to supply power to California utilities at below the market rate for new conventional resources. This assumption has a modest, upward impact on the total cost of complying with a 33% RPS.

Figure 13. Developer Levelized Cost of Generation by Technology Type[51]



[51] This analysis assumes a 20-year PPA with an independent developer. Costs are expressed in 2008 dollars. The renewable technology costs within each technology vary due to project size and location. The CCGT costs vary by natural gas prices.

Determining project value based on avoided costs and environmental scoring

Using the data sources described above, projects are ranked using a modified version of RETI's "net value" approach. The net value is the developer cost of energy from the renewable resource minus the value the resource provides. This value includes avoided energy costs, avoided capacity costs, and avoided GHG allowances purchases. This analysis placed a heavy emphasis on projects that either have a PPA or are in negotiations with a California IOU based on demonstrated commercial interest by treating developer costs as "sunk"[52] for ranking purposes.

In addition to using the avoided costs to rank projects, the study team also determined an environmental score for each project. Starting with the RETI Environmental Working Group's assessment, a project scoring system was developed that considers five additional environmental permitting risk factors, which are described below. This composite environmental metric aims to discern individual projects that may have the fastest or the slowest environmental permitting timelines. After totaling the five factors, projects with the lowest scores are associated with the lowest permitting risk and fastest permitting timelines. Each of these five risk categories was converted into a cost factor to incorporate into the RPS Calculator.

Table 18. Environmental Permitting Risks Factored into Renewable Project Rankings

Factor	Description
Factor 1: All RETI Environmental Issues	Captures total ranking score of each renewable resource zone that the RETI Environmental Working Group defined.
Factor 2: Transmission Footprint	Emphasizes the constraint new transmission line right-of-way represents since the permitting of new transmission lines can be especially time-consuming and challenging.
Factor 3: Pre-Identified versus Proxy Projects[53]	Since proxy projects lack a project sponsor, they are likely to take substantially longer to permit than the "pre-identified projects" that have been developed by specific project developers.
Factor 4: Proximity to Sensitive Lands	Captures visual and aesthetic impacts (views from sensitive lands are generally the highest priority for protection), cumulative impacts, and public opposition. Siting of generation or transmission near sensitive lands generally increases the likelihood of public opposition.
Factor 5: Projects on Federal Land	Federal site permitting can take much longer than the state-only process due to requirements to comply with the NEPA, often in addition to the state CEQA requirements.[54]

[52] These projects are assumed to be available at zero cost for ranking purposes. This ensures that projects with active developer interest are selected first inside each zone, and increases the odds that a zone with active projects is selected. These projects are assigned a cost based on generic resource characterizations when calculating the cost impacts.

[53] RETI identified projects "proxy projects," or projects located in areas with resource potential, even though there was no project sponsor.

[54] It also appears that federal land management agencies are understaffed to handle the significant number of pending (and anticipated) applications for renewable generation and transmission projects, thus the additional consideration of this factor in the scoring system.

Cost Metrics and Sensitivity Analysis

E3 estimated California's annual electricity expenditures in 2020, which is the combined revenue requirement of all of California's utilities (IOU and POU). In addition to the cost of constructing new resources, E3 projected changes in utility costs in a number of areas such as transmission, distribution, fuel costs, and CO_2 allowance price. The result is a projection of California's total electricity expenditures in 2020 under each of the cases. Changes in the state's total electricity expenditures between the 20% RPS Reference Case and the 33% RPS cases represent the incremental costs of complying with a 33% RPS. Sensitivity analysis was then conducted for key variables such as natural gas prices and CO_2 allowance prices, load growth, and solar PV costs.

E3 also calculated the average electricity cost per kWh in 2020, which is the statewide electricity expenditures divided by total retail sales. While this metric is informative, it does not show the bill impact for different customer classes. California's retail rate designs vary for each electric utility in the state, so the bill impacts of achieving a 33% RPS could be somewhat higher or somewhat lower for any individual household or business. For example, the IOU residential rates for lower levels of usage are currently capped at 2001 levels as a result of AB 1X,[55] passed in the immediate aftermath of the California Energy Crisis. This rate cap would last until 2022 under current law, so absent a change to these provisions, the costs of achieving 33% RPS could not be recovered from these sales for lower levels of usage. This would have the effect of increasing the "per kWh" charge, or cost of a 33% RPS that is levied on all remaining usage. As a result, non-residential customers would see proportionately higher bills than they would if all customer usage was billed for RPS costs. A detailed analysis of the distributional impacts of a 33% RPS on customers was beyond the scope of this analysis.

Table 19. Cost Metrics

Metric	Definition
Statewide electricity expenditures in 2020	Combined revenue requirement of all California utilities (IOU and POU)
Average electricity cost per kWh in 2020	Statewide electricity expenditures divided by total retail sales

Development of Renewable Cases

In order to compare the costs of a 33% RPS to existing state policy, E3 created a 20% RPS Reference Case. Next, E3 created a 33% RPS Reference Case, representing primarily the results of recent IOU solicitations, as well as three alternative 33% RPS cases to test different policy objectives. The 33% RPS Reference Case prioritizes all projects that have resulted from recent solicitations (approved, pending approval, or short-listed) and are therefore represented in the CPUC Database. The alternative 33% RPS cases prioritize projects that the CPUC has *approved*, but do not prioritize projects that are *pending approval* or *short-listed*. This results in an additional 39 TWh of energy that can be met through selection of other renewable resources from the RETI and E3 databases.

[55] The CPUC issued D.01-05-064 on May 14, 2001 to implement AB 1X: http://docs.cpuc.ca.gov/PUBLISHED/FINAL_DECISION/7185.htm

20% RPS Reference Case

The 20% RPS Reference Case assumes that California utilities procure only enough resources to maintain the current statutory target of a 20% RPS in 2020. This case focuses primarily on resources that can be integrated through new transmission corridors that are already approved by the CPUC or are expected to be added in the near term such as Tehachapi and Sunrise.

33% RPS Reference Case

The 33% RPS Reference Case places the heaviest emphasis on projects in the ED Database, which represent projects that have been short-listed or contracted by IOUs. The 33% RPS Reference Case assumes that most of the projects in that database are developed by 2020. Since IOUs have selected a substantial number of solar thermal and solar PV projects in recent solicitations, these resources are heavily represented in the 33% RPS Reference Case. The case includes 7,200 MW of solar thermal and 3,200 MW of central utility-scale solar PV resources, along with other wind, geothermal, and biomass resources. As such, this case probably represents a high bookend on the amount of solar thermal that could realistically be developed by 2020.

High Wind Case.

The High Wind Case replaces most of the solar resources in the 33% RPS Reference Case with wind resources in California and Mexico. Instead of relying on the higher cost solar thermal resources that are heavily represented in recent IOU solicitations, this case represents the lowest-cost resources that can be developed in-state without assuming major, new interstate transmission.

High Out-of-State Delivered Case

The High Out-of-State Delivered Case assumes that new, long-distance transmission lines are developed to access high-quality renewable resources from out-of-state resources in the WECC. The case includes a 3,000 MW transmission line bringing wind energy from Wyoming and a 1,500 MW transmission line bringing principally geothermal resources from northern Nevada. Like the High Wind Case, this case relies more heavily on wind than solar resources. However, in this case a larger proportion of the wind is anticipated to come from outside of California.

High DG Case

The High DG Case is intended to examine the implications of the state relying heavily on distributed resources such as solar PV to meet a 33% RPS. Motivations for such a case include increasing public opposition to large transmission or generation projects that have long development times, large upfront investments, and environmental complexities. The High DG Case assumes that it would be difficult or impossible to construct new, high-voltage transmission projects to accommodate renewable resources, beyond those lines assumed for the 20% RPS Reference Case. To fill the renewable resource need, this case relies on estimates of the technical potential of solar PV and other distributed renewable resources. It does not fully examine the approaches needed to deploy this case, however.

Table 20. Assumptions in all 2020 Cases

Category	Assumption
Load forecast	Energy Commission's 2007 IEPR reference case or mid-case load forecast
Fuel price forecast	The Market Price Referent methodology, updated with new natural gas prices, was used to develop the base case forecast
CO_2 allowance price forecast	The Market Price Referent methodology was used for CO_2 price forecasts to develop the base case forecast
Energy efficiency achievement	No incremental energy efficiency assumed beyond what is already incorporated in the Energy Commission's 2007 IEPR load forecast
Demand response achievement	No incremental demand response assumed beyond what is already incorporated in the Energy Commission's 2007 IEPR load forecast
Combined Heat and Power (CHP) achievement	Energy Commission 2007 IEPR base-case load forecast assumption for CHP penetration
Customer-installed solar PV	Energy Commission 2007 IEPR load forecast, 847 MW nameplate of customer-installed PV[56]
GHG allowance allocation	GHG emissions allowances are auctioned. Auction revenue from allowances equal to 2008 electricity sector emissions is returned to utilities
Resource characterizations	Reference case resource cost assumptions based on RETI and E3 data for renewable generation and the Market Price Referent[57] for new combined-cycle gas turbines

[56] The 2007 IEPR load forecast assumed 847 MW of customer-side PV, a fraction of the 3,000 MW California Solar Initiative goal.

[57] D.08-10-026 approved the 2008 MPR Methodology. Resolution E-4214 calculated the 2008 MPR based on this methodology. MPR-related documents can be accessed on the CPUC website: http://www.cpuc.ca.gov/PUC/energy/Renewables/mpr

TIMELINE METHODOLOGY

In order to evaluate the feasibility of achieving the 33% RPS Reference Case by 2020, this study determined reasonable timelines for the sequence of steps required to plan, permit, and construct the generation and transmission identified in the 33% RPS Reference Case. This assessment provides a pragmatic "reality check" of the state's ability to reach California's 33% RPS target since it realistically assesses implementation timelines as well as major factors and uncertainties driving those timelines. This study only performed a timeline implementation analysis on the 33% RPS Reference Case since this case represents the IOUs' current procurement strategy. The 33% RPS Reference Case, however, represents only one of many plausible development scenarios that could meet a 33% RPS. In addition, an implementation assessment of the distributed and out-of-state resources that contributed to the 33% RPS Reference Case was not performed.

The study team began its assessment by identifying the key milestones and lead times involved in bringing new transmission and generation online. Distinct sets of milestones were identified for different categories of generation and transmission projects, and the team analyzed empirical evidence as to the timing of the completion of those milestones. Various simplifying assumptions were made, as detailed below. These assumptions result in somewhat optimistic estimates of the time required to develop renewable energy.

Renewable technology assumptions:

- Over the next 10 to 15 years, all currently proposed renewable projects will obtain the necessary financing to construct the project and commence operations
- All of the proposed renewable energy technologies will operate as proposed
- Renewable energy development companies will succeed in bringing all of their projects online
- There will be no manufacturing bottlenecks or other supply chain constraints, which could slow project development

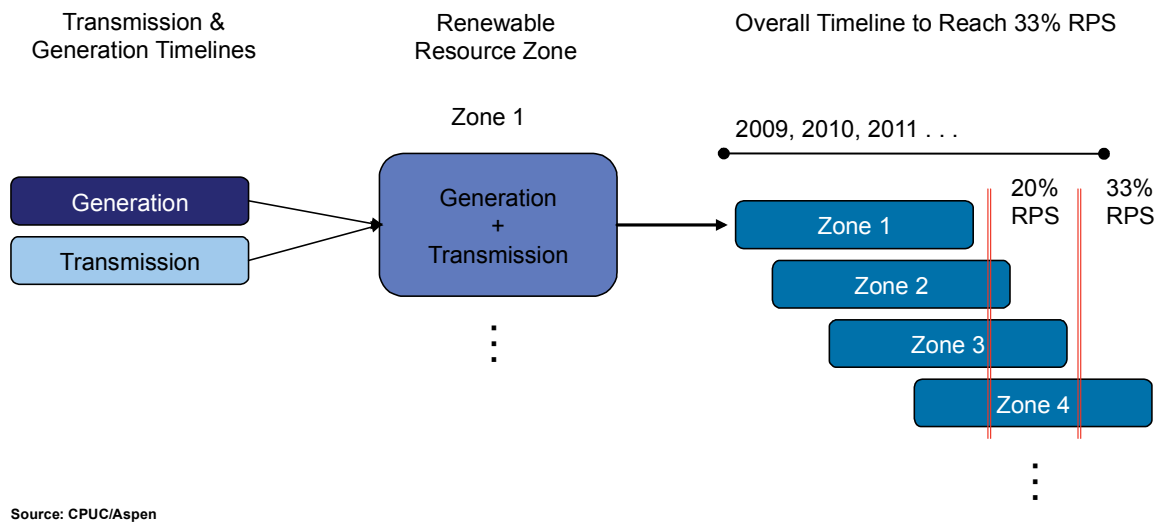
Transmission assumptions:

- The transmission expansions identified are conceptual and are meant to provide a general sense of the number of major new transmission lines and the number of applications for a CPCN or permit application required to access the renewable resources included in the 33% RPS Reference Case. These conceptual expansions have not been subject to detailed transmission planning and project design
- Does not identify additional transmission upgrades that would likely be needed within the study period to accommodate load growth and reliability requirements, and to make the renewable resources included in the 33% RPS Reference Case fully deliverable to load centers
- Transmission lines assumed to be sited within United States BLM utility corridors (if on BLM land) or adjacent to existing transmission lines (if not on BLM land), though distance from existing lines was not estimated

The study team then created generic timelines for the generation and transmission facilities needed to achieve the 33% RPS Reference Case. Once the building blocks of the individual generation and transmission timelines were in place, these individual timelines were combined into one overall timeline for the 33% RPS Reference Case.

Figure 14 illustrates the process of combining the generic transmission and generation timelines into timelines for each resource zone, and subsequently combining the individual resource zone timelines into the three illustrative timelines for achieving the full 33% RPS Reference Case portfolio.

Figure 14. Timeline Development Flow Chart



<u>Generic generation and transmission timelines</u>

Transmission planning, permitting, and construction require substantial lead times, generally longer than those required for generation facilities. The timelines for transmission and generation facilities are interdependent. The completion date of a new transmission line dictates the earliest possible online date for a generation project that needs that transmission to deliver the energy to load. The relationship between transmission and generation affects a renewable developer's willingness to invest in the project development efforts. Renewable developers will only invest in project development if they believe the required transmission will be available when needed and at a cost suitable for their project's economics. Generation development in any resource zone can occur at the same time that transmission development is occurring for that zone, but generation development may extend beyond completion of the transmission line due to the challenges associated with simultaneously completing the transmission and generation.

Generic Transmission Timeline

The 33% RPS Reference Case assumes the development of seven major generic new transmission lines to the selected resource zones, beyond those new lines already assumed in the 20% RPS Reference Case.

This analysis only identifies and evaluates the large (200 kV and above) transmission lines that require a CPCN from the CPUC or a similar approval from a POU, because of the lengthy review required for such major lines. Several smaller lines would likely be required before 2020 to maintain grid reliability under the 33% RPS Reference Case, but because these lines are generally reviewed and permitted much faster than the large transmission lines, they are not considered to be critical path and are not considered in this analysis.

The typical timeline for new transmission is estimated to be approximately eight years, as shown in Table 21. The transmission planning timeline of 24 months takes into consideration increased efficiencies expected from GIPR[58] currently taking place at the California ISO as well as coordination of interconnection studies with the overall transmission planning process. Although the steps below are shown in sequence, portions of the work often proceed in parallel. Section 4 of this report describes efforts to gain efficiencies in the transmission development process by further coordinating the steps below.

Table 21. Generic Timeline for an IOU-Owned Transmission Line > 200 kV, Based on Past Transmission Permitting Experience

Transmission Development Process	Timing
Transmission Planning Process • ISO interconnection studies/transmission planning and board approval • IOU development of plan of service (may overlap with the above)	24 months
PEA/CPCN Application preparation by IOU[59]	18 months
CEQA/NEPA review and environmental documentation by local, state, and/or federal agency, resulting in an environmental impact statement	24 months
CPUC approval	3 months
Final design and construction	30 months
TOTAL	**99 months (8.25 years)**

[58] GIPR is expected to increase the speed and efficiency of studying interconnection requests by planning common transmission solutions for groups of generation projects and integrating such planning into the California ISO annual transmission planning process.
[59] PEA = Proponent's Environmental Assessment.

While the CPUC averages approximately 18 months for CEQA review and CPCN approval for transmission siting cases in general, more conservative assumptions were used here to account for the likely larger and more controversial nature of these new required projects. For purposes of this assessment, a transmission line is assumed to be 100 miles long, with some segments on federal land, and located entirely within the boundaries of California. The duration of final design and construction varies widely, however, depending on the utility's readiness to move forward with the route that is finally selected. This schedule can be shortened up to three months if the utility were to start preliminary engineering immediately upon issuance of the draft Environmental Impact Report (EIR) since the transmission route usually does not change significantly from the draft to the final EIR.

Generic Generation Timeline

The 33% RPS Reference Case requires the development of nine new resource zones, comprising approximately 19 GW. The analysis suggests that the nine resource zones can be accessed by seven new transmission lines. The typical timeline estimated for renewable resource selection and development is 42 to 93 months (3.3 to 7.8 years), depending on the type of renewable generation. The components of the timeline are shown in Table 22.

Table 22. Generic Renewable Generation Timeline for an IOU-Contracted Resource

Renewable Project Development Process	Timing
Request for Offer issuance and review	3 months
Negotiation of PPA and submittal to CPUC	5-12 months
CPUC review and approval of PPA	4-6 months
Project design, site control, and permit application preparation	12 months on average
Permitting and development: Renewable resource permitting and development, including environmental documentation by municipality, county, Energy Commission, and/or federal lead agency	18-60 months
TOTAL	**42-93 months (3.5 - 7.8 years)**

The permitting and development section in Table 22 includes a range of timeframes for permitting at various agencies and a range of construction durations from under one year for the smallest projects up to multiple years for more complex facilities. The permitting requirements for generation are dictated by technology type, location, and size. There are six categories of generation projects for purposes of permitting, each with a distinct timeline depending on the complexity of environmental permitting and the agencies involved. Similarly, construction durations vary by resource type and size. The timelines in Figure 15 and Figure 16 present estimates of permitting and construction timelines for various categories of generation projects. These timelines represent expected (not minimum or maximum) timelines, and are based on a review of recently developed renewable generation projects. This information was used to aggregate renewable projects in each zone to determine a timeline for each resource zone needed for a 33% RPS.

Figure 15. Standard Permitting Timelines for Categories of Renewable Generation Projects

Project Size & Jurisdiction	Resource Type	Year 1	Year 2	Year 3	Year 4
SMALL - LOCAL	Any renewable (<50 MW)	Application Prep	City / County CEQA		
SMALL - FEDERAL	Any renewable (<50 MW) on Federal land	Application Prep	City / County CEQA Federal Agency NEPA		
LARGE - LOCAL	Solar PV, Wind	Application Prep	City / County CEQA		
LARGE - STATE	Geothermal, Solar Thermal, Biomass, Biogas (> 50 MW)	Application Prep	CEC CEQA Equivalent		
LARGE - FEDERAL + STATE	Geothermal, Solar Thermal, Biomass, Biogas (> 50 MW) on Federal land	Application Prep	CEC CEQA Equivalent Federal Agency NEPA		
LARGE - FEDERAL + LOCAL	Solar PV, Wind	Application Prep	City / County CEQA Federal Agency NEPA		

Source: CPUC/Aspen

Figure 16. Standard Construction Timelines for Categories of Renewable Generation Projects[60]

Resource	Size	Year 1	Year 2	Year 3	Year 4
SOLAR PV	Small (<50 MW)	12 months			
SOLAR PV	Large (>50 MW)	25 months			
SOLAR THERMAL	Small (<50 MW)	16 months			
SOLAR THERMAL	Large (>50 MW)	35 months			
WIND	Small (<50 MW)	13 months			
WIND	Large (>50 MW)	20 months			
BIOMASS, GEOTHERMAL	Small (<50 MW)	12 months			
BIOMASS, GEOTHERMAL	Large (>50 MW)	26 months			

Source: CPUC/Aspen

[60] Timelines can vary greatly within the size ranges presented in the figure, i.e. between a 5 MW and a 49 MW plant, and between a 50 and 500 MW plant. The small number of completed large-scale PV and solar thermal plants also makes it very difficult to generalize construction times; the large solar PV and thermal plants contracted for development in California would be the first projects at that scale globally. The construction duration estimates here are meant to be illustrative.

Appendix C: Resource Zones and Resource Mix for each Renewable Case

RESOURCE ZONES USED IN RPS CALCULATOR

Resource Zone Name	Description or Source
Alberta	GHG Calculator Zone
Arizona-Southern Nevada	GHG Calculator Zone
Baja	RETI Competitive Renewable Energy Zone (CREZ)
Barstow	RETI CREZ
British Columbia	Combination of RETI CREZ/ GHG Calculator Zone
Carrizo North	RETI CREZ
Carrizo South	RETI CREZ
Colorado	GHG Calculator Zone
Cuyama	RETI CREZ
Distributed Biogas	Biogas resources from RETI and E3 that are assumed to be able to come online without substantial new transmission
Distributed Biomass	Biomass resources from RETI that are assumed to be able to come online without substantial new transmission
Distributed CPUC Database	Resources of all types from the CPUC Database that are assumed to be able to come online without substantial new transmission
Distributed Geothermal	Geothermal resources from RETI that are assumed to be able to come online without substantial new transmission
Distributed Solar	Solar resources from RETI that are assumed to be able to come online without substantial new transmission
Distributed Wind	Wind resources from RETI that are assumed to be able to come online without substantial new transmission
Fairmont	RETI CREZ
Imperial East	RETI CREZ
Imperial North	RETI CREZ
Imperial South	RETI CREZ

Resource Zone Name	Description or Source
Inyokern	RETI CREZ
Iron Mountain	RETI CREZ
Kramer	RETI CREZ
Lassen North	RETI CREZ
Lassen South	RETI CREZ
Montana	GHG Calculator Zone
Mountain Pass	RETI CREZ
Needles	RETI CREZ
NE Nevada	GHG Calculator Zone
New Mexico	GHG Calculator Zone
Northwest	GHG Calculator Zone
Not Assigned	Resources listed in RETI database that are a) not assigned to a geographic zone and b) assumed to require new transmission
Owens Valley	RETI CREZ
Out-of-State Early	Out-of-state resources from CPUC database that are either under contract or short-listed and expected to come online in the near term
Out-of-State Late	Out-of-state resources from CPUC database that are either under contract or short-listed and expected to come online in the long term, plus 1,400 MW of additional out-of-state wind resources assumed to be available to California utilities
Palm Springs	RETI CREZ
Pisgah	RETI CREZ
Remote DG	RETI estimates of PV potential modified for RPS Calculator
Reno Area/Dixie Valley	GHG Calculator Zone
Riverside East	RETI CREZ
Round Mountain	RETI CREZ
San Bernardino - Baker	RETI CREZ
San Bernardino - Lucerne	RETI CREZ
San Diego North Central	RETI CREZ
San Diego South	RETI CREZ
Santa Barbara	RETI CREZ

Resource Zone Name	Description or Source
Solano	RETI CREZ
South Central Nevada	GHG Calculator Zone
Tehachapi	RETI CREZ
Twentynine Palms	RETI CREZ
Utah-Southern Idaho	GHG Calculator Zone
Victorville	RETI CREZ
Wyoming	GHG Calculator Zone

RESOURCE ZONE AND RENEWABLE MIX FOR ALL RPS CASES[61]

20% RPS Reference Case

Resource Zones Selected in 20% RPS Reference Case		
	MW	GWh
Tehachapi	3,000	8,862
Distributed CPUC Database	525	3,118
Solano	1,000	3,197
Out-of-State Early	2,062	6,617
Imperial North	1,500	9,634
Riverside East	1,350	3,153
Total	9,437	34,581

Resource Mix – 20% RPS Reference Case						
	In-State		Out-of-State		Total	
	MW	GWh	MW	GWh	MW	GWh
Biogas	30	223	-	-	30	223
Biomass	241	1,687	87	610	328	2,297
Geothermal	1,240	9,515	58	445	1,298	9,959
Hydro - Small	22	95	15	66	37	161
Solar PV	830	1,774	-	-	830	1,774
Solar Thermal	996	2,431	-	-	996	2,431
Wind	4,016	12,240	1,902	5,497	5,917	17,737
Total	7,375	27,965	2,062	6,618	9,436	34,582

[61] Some of the MW and GWh totals may be off by one digit. This is due to rounding.

33% RPS Reference Case

Additional Resource Zones Selected in 33% RPS Reference Case	MW	GWh
Resources from 20% RPS Reference Case	9,437	34,581
Mountain Pass	1,650	4,041
Carrizo North	1,500	3,306
Out-of-State Late	1,934	5,295
Needles	1,200	3,078
Kramer	1,650	4,226
Distributed Biogas	249	1,855
Distributed Geothermal	175	1,344
Fairmont	1,650	5,003
San Bernardino - Lucerne	1,800	5,020
Palm Springs	806	2,711
Baja	97	321
Riverside East Incremental	1,650	3,869
Total	**23,798**	**74,650**

Resource Mix – 33% RPS Reference Case	In-State		Out-of-State		Total	
	MW	GWh	MW	GWh	MW	GWh
Biogas	279	2,078	-	-	279	2,078
Biomass	391	2,737	87	610	478	3,346
Geothermal	1,439	11,027	58	445	1,497	11,471
Hydro - Small	25	111	15	66	40	177
Solar PV	3,235	6,913	-	-	3,235	6,913
Solar Thermal	6,764	16,652	534	1,304	7,298	17,956
Wind	7,573	22,899	3,399	9,809	10,972	32,709
Total	**19,706**	**62,417**	**4,093**	**12,234**	**23,799**	**74,650**

High Wind Case

Additional Resource Zones Selected in High Wind Case	MW	GWh
Resources from 20% RPS Reference Case	9,437	34,581
Distributed Biogas	249	1,855
Distributed Geothermal	175	1,344
San Bernardino - Lucerne	1,800	5,020
Palm Springs	806	2,711
Distributed Wind	468	1,289
Out-of-State Late	1,934	5,295
Fairmont	1,650	5,003
Baja	1,500	4,966
San Diego South	903	2,583
Round Mountain	500	2,759
Distributed Biomass	162	1,138
Pisgah	1,800	4,589
Barstow	450	1,163
Riverside East Incremental	150	354
Total	**21,984**	**74,650**

Resource Mix – High Wind Case						
	In-State		Out-of-State		Total	
	MW	GWh	MW	GWh	MW	GWh
Biogas	279	2,078	-	-	279	2,078
Biomass	634	4,442	87	610	721	5,052
Geothermal	1,655	12,541	58	445	1,713	12,985
Hydro - Small	22	95	15	66	37	161
Solar PV	1,162	2,483	-	-	1,162	2,483
Solar Thermal	3,163	7,715	534	1,304	3,697	9,019
Wind	9,575	28,419	4,802	14,454	14,376	42,873
Total	**16,490**	**57,773**	**5,496**	**16,879**	**21,985**	**74,651**

High Out-of-State Delivered Case

Additional Resource Zones Selected in High Out-of State Delivered Case	MW	GWh
Resources from 20% RPS Reference Case	9,437	35,051
Distributed Geothermal	175	1,344
Distributed Biogas	249	1,855
Out-of-State Late	1,934	5,295
San Bernardino - Lucerne	1,800	5,043
Reno Area/Dixie Valley	1,500	8,596
Palm Springs	806	2,711
Round Mountain	500	2,759
Wyoming	3,000	10,493
Distributed Biomass	162	1,138
Fairmont	140	402
Riverside East Incremental	150	354
Total	19,853	74,651

Resource Mix – High Out-of State Delivered Case	In-State		Out-of-State		Total	
	MW	GWh	MW	GWh	MW	GWh
Biogas	279	2,078	-	-	279	2,078
Biomass	575	4,030	87	610	662	4,640
Geothermal	1,655	12,541	938	7,142	2,593	19,683
Hydro - Small	22	95	27	131	49	226
Solar PV	969	2,072	-	-	969	2,072
Solar Thermal	2,101	5,153	534	1,304	2,635	6,457
Wind	5,756	17,681	6,910	21,813	12,666	39,494
Total	11,357	43,650	8,496	31,000	19,853	74,650

High Distributed Generation Case

Additional Resource Zones Selected in High Distributed Generation Case	MW	GWh
Resources from 20% RPS Reference Case	9,437	34,581
Distributed Biogas	249	1,855
Distributed Geothermal	175	1,344
Distributed Wind	468	1,289
Out-of-State Late	1,934	5,295
Distributed Biomass	162	1,138
Remote DG	9,000	19,236
Distributed Solar	5,186	9,558
Riverside East Incremental	150	354
Total	**26,761**	**74,650**

Resource Mix – High Distributed Generation Case						
	In-State		Out-of-State		Total	
	MW	GWh	MW	GWh	MW	GWh
Biogas	279	2,078	-	-	279	2,078
Biomass	403	2,825	87	610	490	3,435
Geothermal	1,415	10,859	58	445	1,473	11,303
Hydro - Small	22	95	15	66	37	161
Solar PV	15,068	30,678	-	-	15,068	30,678
Solar Thermal	1,095	2,674	534	1,304	1,629	3,978
Wind	4,484	13,529	3,302	9,488	7,785	23,017
Total	**22,766**	**62,738**	**3,996**	**11,913**	**26,761**	**74,650**

Exhibit 26

PV Grid Connected Market Potential under a Cost Breakthrough Scenario

Residential Home
Source: Kyocera Solar

September 2004

Toyota Motor Sales, 500 kW.
Source: PowerLight Corporation

Maya Chaudhari
Lisa Frantzis
Dr. Tom E. Hoff

The Energy Foundation
Toward a sustainable energy future

The Energy Foundation

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NAVIGANT CONSULTING

Table of Contents

1 » Introduction

2 » Executive Summary

3 » Market Potential for Grid Connected PV

4 » Market Barriers

5 » Attractive States for PV

6 » Appendix

Table of Contents

1 » Introduction

2 » Executive Summary

3 » Market Potential for Grid Connected PV

4 » Market Barriers

5 » Attractive States for PV

6 » Appendix

The Energy Foundation commissioned this study to evaluate the market potential for PV in 2010 under a cost breakthrough scenario.

- The Energy Foundation believes that PV will play an important role in America's energy future and that the U.S. economic, energy security and environmental benefits are large.
  - The future for the PV industry is bright under either business-as-usual or technology breakthrough scenarios.
- This work was undertaken to develop an estimate of how large the market for PV systems would be under certain assumptions about future installed-cost reductions.
  - One objective was to increase investor confidence in the PV industry, and to encourage state and federal policy makers to continue and expand existing forms of policy and financial support for PV industry expansion.
- Navigant Consulting, Inc. (NCI) assessed the market potential for PV in 2010, if an aggressive investment-led breakthrough in installed system price of $2/Wp[1] is achieved.
  - We emphasize that these cost reductions can only be achieved with strong, continued government support in the near term that creates a positive investment climate for private investors.
- NCI conducted this study in collaboration with Clean Power Research.

1) All data is in $/Wpdc unless otherwise stated.

The objective of this study is to answer three key questions:

What is the grid connected[2] market potential for PV under a cost breakthrough scenario and how can this be achieved?

What is the grid connected market potential for PV under a cost breakthrough scenario?

- What is the grid-connected market potential if the average installed price for PV is $2/Wp (based on a cost breakthrough) in 2010 in the *roof-top* Residential and Commercial sectors? What is the sensitivity for both $1/Wp and $3/Wp?
- What is a methodology that can be used to estimate the impact for the Utility[1] sector? What is the potential demand in the utility sector in California under this cost scenario?

How can this market potential be achieved?

- What are the other barriers that need to be addressed to encourage further development of the PV market?

Which are potentially the most attractive states for PV installations in 2010?

- What are the economics of PV in each state, and what favorable incentives exist to support market expansion?

The scope of this study is limited to the grid-connected[3] market in the U.S.

1) The Utility sector refers to PV for central generation or installations at utility substations.
2) Includes both consumer and utility side of the meter; both are addressed in the report using different methodologies. In the U.S., grid connected PV accounted for around 55% of the total market in 2003 and is expected to increase its share over the next decade to 70%.
3) The other markets are off-grid (habitation and industrial) and consumer goods.

Table of Contents

1 » Introduction

2 » Executive Summary

3 » Market Potential for Grid Connected PV

4 » Market Barriers

5 » Attractive States for PV

6 » Appendix

The demand for PV is estimated assuming a breakthrough in installed PV system price by 2010.

Segment	System Size (kWpdc)[2]	Installed System Price ($/Wpdc) in 2010			Cost Break-through Assumed (Base vs BAU in %)
		Base-case	Sensitivity cases	Business-as-usual (BAU) case [1]	
Residential	2.5 kWp	$2.50	$ 1.25 $ 3.75	$ 5.30	53%
Commercial: Small/ Medium system size	15.0 kWp	$ 2.20	$ 1.10 $ 3.30	$ 4.65	53%
Commercial: Large system size	100 kWp	$ 2.00	$ 1.00 $ 3.00	$ 4.25	53%
Utility Central Plant	5 MWp	$ 2.00	$ 1.00 $ 3.00	$ 4.00	50%

1) BAU is NCI's best estimate of what installed system costs will be in 2010 given recent trends in system cost reductions. NCI has interviewed PV manufacturers, installers, and balance of system suppliers to derive these estimates., 2004. This rate of cost reduction can be achieved with continued government and customer support for PV. No state buy-downs/subsidies are assumed in the 2010 prices shown, but the continued decline in prices in the near term requires continuation of customer incentives in the United States, Europe, and Japan to support plant capacity expansions.

2) Wpdc is the amount of power a PV device will produce at noon on a clear day with sun approximately overhead when the cell is faced directly toward the sun. DC is direct current. The system size was not a constraint on the market size estimated later in the report. The market size was primarily a function of available roof space and project economics. The PV system size is used only to calculate the payback period. The market estimation is driven primarily by roof space, payback and market-penetration rates.

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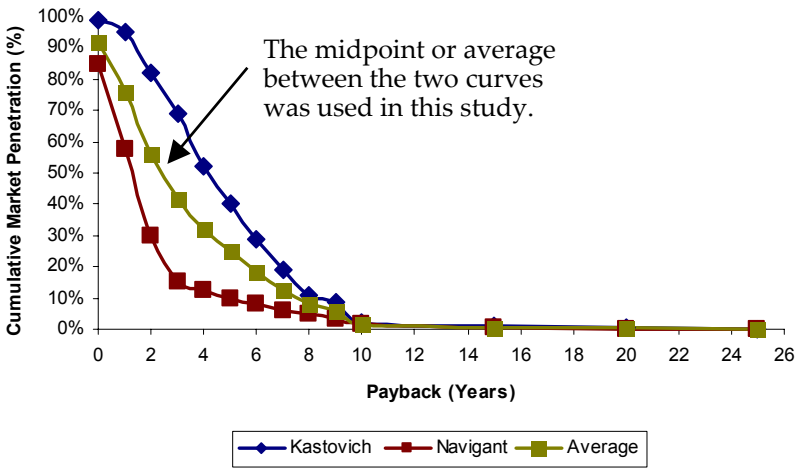
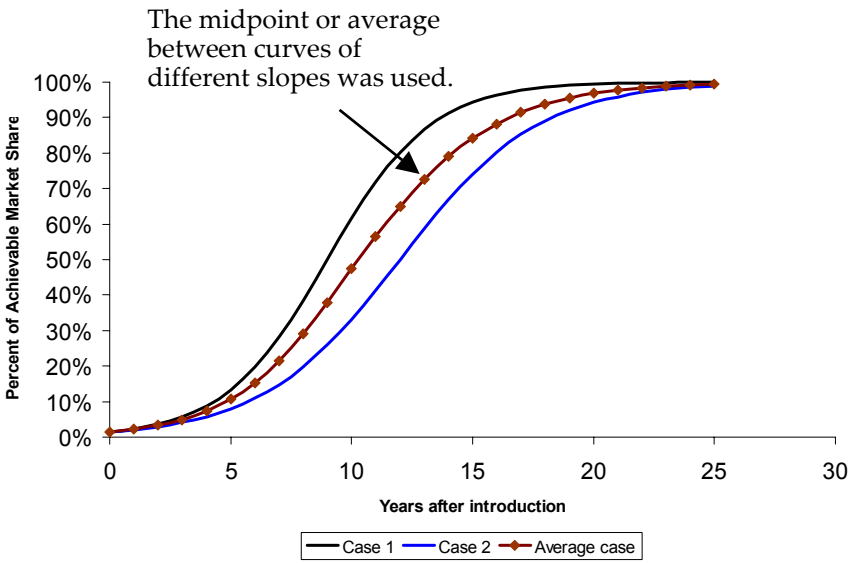
Two curves were used to estimate demand for PV: one links payback to penetration, and the other projects build-up of annual demand.

Payback vs. Cumulative Market Penetration Curves



- The curves provide the cumulative market penetration 10-20 years after product introduction, as a function of payback. These curves were applied to the total technical market potential (available roof space) that can be captured under different payback assumptions.
- The Kastovich curve is more aggressive than the Navigant curve: a midpoint between the two was thus considered in the analysis.

Typical S-Curve



- The S-Curve provides the rate of adoption of technologies, which is a function of the technologies characteristics and market conditions. The curve begins with a slow start, followed by steep growth, and then a plateau which is characteristic of many technological capabilities and product life cycles.
- An average of two curves was used, given the many factors that will impact penetration of PV.

The potential grid-connected residential and commercial sector demand for PV in 2010 at a system price of $2.00-2.50/Wpdc is estimated at 2.9 GWp, valued at ~$6.6 billion annually.

Potential Annual Demand in 2010

Residential

System size =	2.5 kW		
Technical Market (MWp) =	385,790		
System Price ($/Wpdc)	**MWp**	**% mkt share**	**$ billion**
$1.25	5,344	1.39%	6.7
$2.50	958	0.25%	2.4
$3.75	296	0.08%	1.1
$5.30	160	0.04%	0.8

Commercial

Commercial - Small/Medium and Large Total			
System size =	15 kWp, 100 kWp		
Technical Market (MW) =	326,074		
System Price ($/Wpdc)	**MWp**	**% mkt share**	**$ billion**
$ 1.00 - 1.10	5,941	1.82%	6.5
$ 2.00 - 2.20	1,942	0.60%	4.2
$ 3.00 - 3.30	852	0.26%	2.8
$ 4.25 - 4.65	506	0.16%	2.3

Grid Connected - Total

Technical Market (MW) =	711,864		
System Price ($/Wpdc)	**MWp**	**% mkt share**	**$ billion**
$ 1.00 - 1.25	11,285	1.59%	13.1
$ 2.00 - 2.50	2,901	0.41%	6.6
$ 3.00 - 3.75	1,148	0.16%	3.9
$ 4.25 - 5.30	666	0.09%	3.2

Key Comments

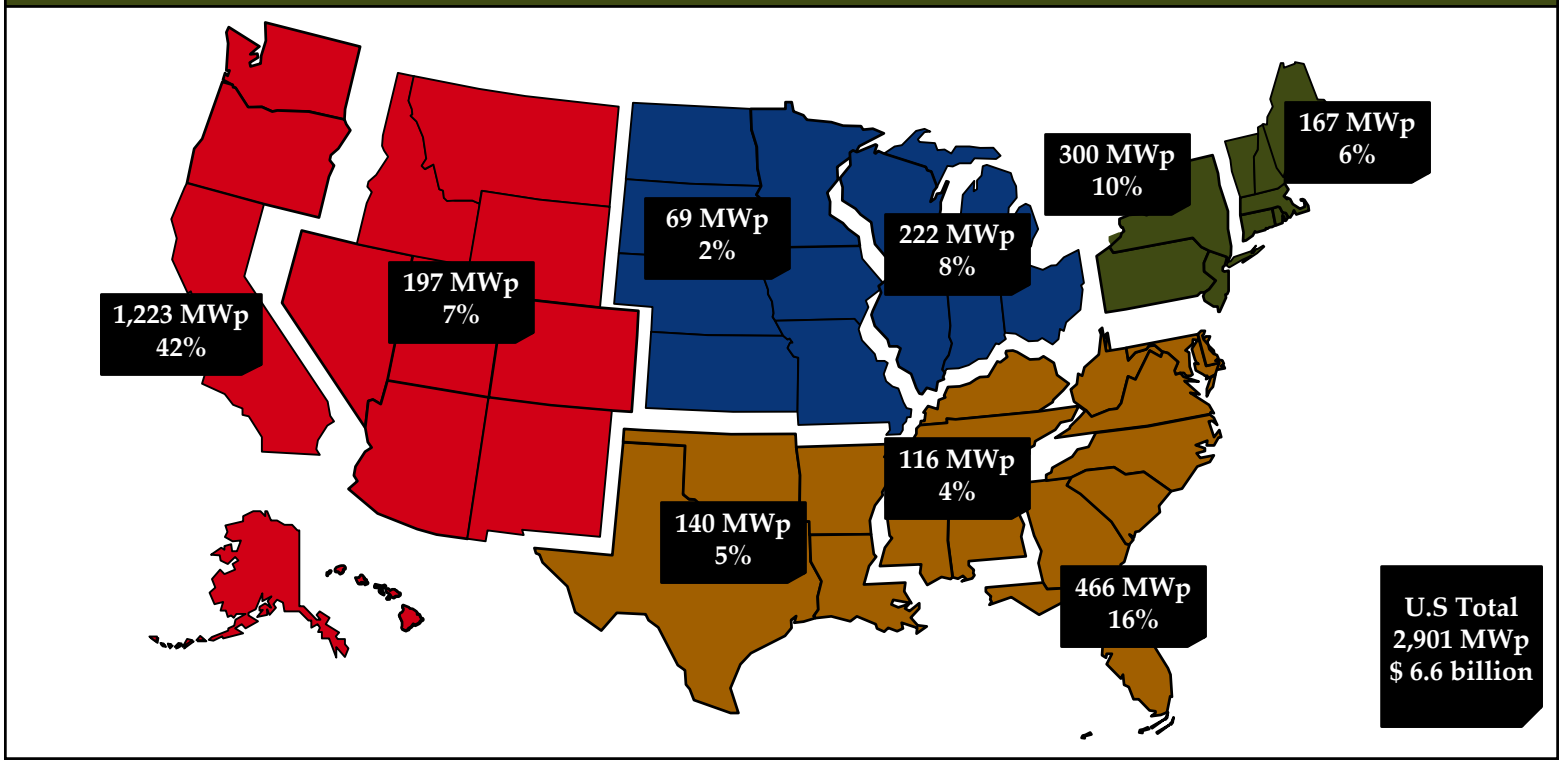
- The annual demand for PV in the year 2010 is calculated by applying the S-curve discussed earlier to the likely cumulative market potential in 2025, and is estimated at around 6% of the same. (see page 36 for further details).
- As can be seen, this demand estimation is highly sensitive to the slope of the S-curve. Moving slightly above or below the S-curve could decrease or increase the 6% share to 3% or 9%.
- The precise position of the PV industry on the S-curve in 2010 is hard to predict, as it depends on many factors including technological developments, investment in manufacturing capacity, market development, consumer behavior and government policies.
- Based on the analysis conducted, it is estimated that the potential demand in 2010 at a system price of $2.00-2.50/Wp is around 2.9GWp[1], assuming the industry can provide the capacity and marketing infrastructure and would have invested in market development prior to 2010 to make it happen. This is orders of magnitude higher than the 2003 estimated demand of 70MWp, valued at around $750-800 million, which may be considered to be constrained due to inadequacy of government incentives (across all states) and funds.[2]

1) This figure is consistent with informal discussions NCI had with a major PV manufacturer who indicated that the total (grid-connected and off-grid) potential PV demand in the U.S at a system price of ~$2.00 (which is expected to happen much later than 2010) is around 3GWp.

2) Note that the business-as-usual case projects almost a ten-fold increase in the PV market by 2010, resulting in an annual value of $3.2 billion.

At a system price of $2.00-2.50/Wpdc, the Pacific and Mid-Atlantic regions together account for 52% of the potential residential and commercial sector demand in 2010[1].

Potential Grid Connected Demand in 2010 By Census Region: MWp/year and % Share
Installed System Price: $2.00 – 2.50/Wpdc



1) Potential demand in 2010 by segment (residential, commercial, total) by state and different system price scenarios is provided in the Appendix. Demand in the Pacific and Mid-Atlantic regions is higher primarily because higher retail electricity prices in these regions shorten the payback period for purchasers of PV systems and, therefore, increase the predicted market demand under the model used in this study.

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The potential demand for "central" PV in California in 2010 is estimated at 5-500 MWp annually, depending on natural gas prices and gas turbine (GT) capacity factors.

Central PV Potential Demand in 2010						
Fuel Cost	**$5.0 / MMBTU**			**$3.0 / MMBTU**		
Gas Turbine Capacity Factor	**8%**	**10%**	**15%**	**8%**	**10%**	**15%**
PV System Cost	**Annual Demand in 2010 (MW)**					
$1.00/Wpdc	500	452	312	452	367	201
$2.00/Wpdc	90	20	9	20	12	0
$3.00/Wpdc	5	0	0	0	0	0
$4.00/Wpdc	0	0	0	0	0	0

Demand for central PV is nil when the payback is more than 20 years.

The potential demand for PV could be higher than estimated.

Factors That Could Increase the Demand Estimation
Residential and Commercial Segment
1. Only roof-top applications were considered. Other applications such as ground mounted PV, car ports, curtain walls, and awnings were ignored. These applications currently account for a negligible proportion of the market, but is growing. 2. Utility rates could escalate at a rate higher than assumed, which would reduce the payback period for PV systems leading to higher market penetration. 3. The value for Renewable Energy Certificate (RECs) is assumed to be $0.015/kWh in 2010. A higher REC value due to greater demand, particularly for PV RECs, could improve the economics of a PV system and increase demand. 4. The value proposition at any given location may be better than presented in this report. For example, the demand estimate is based on the average consumption by customers in the residential and commercial segments. Customers with higher consumption in some states like California have higher utility rates. For these customers, PV economics would be much better than for the "average" customer, which could lead to higher penetration within the high consumption customer category. 5. The economic analysis did not consider any state incentives or policies that would proactively encourage demand. 6. Time-of-use rates that monetize the value of PV coincidence with utility peak loads would improve PV economics.
Utility Segment
1. The analysis only looked at PV relative to cost of competing generation technologies, but at some sites the PV installation may have additional value in avoiding need for distribution facility capital investment. 2. Value due to factors such as fuel price risk mitigation, intangibles, etc could also lead to better PV economics and hence higher demand. This is again specific to a utility, depending on their generation mix, tariff structure, community relationships, environmental record, etc.

While this study does not analyze the demand taking into account the above, the Appendix does provide some estimate of potential demand under more aggressive market penetration assumptions.

NAVIGANT CONSULTING

Table of Contents

1 » Introduction

2 » Executive Summary

3 » Market Potential for Grid Connected PV

4 » Market Barriers

5 » Attractive States for PV

6 » Appendix

Table of Contents

3 » Market Potential for Grid Connected PV

Residential and Commercial Segments

Utilities Segment

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There are many factors that drive the demand for PV in residential and commercial applications…

Factor	Issues
PV Economics *Does PV compare favorably with competing technologies?*	• Grid connected PV competes with retail electricity. Unlike grid power, customers incur a high upfront cost and, depending on the level of customer incentives offered by state or utility programs, a high LCOE[1] over the project life to invest in PV. • This economic disadvantage of PV is reduced significantly through government incentives and a growing market for PV environmental attributes such as green tag (renewable energy certificate or REC) trading. • In terms of a purchase decision, different economic metrics are used, such as: - upfront cost - payback period - internal rate of return - net present value - levelized cost of electricity - years till cumulative positive cash flow
Government Policies *Do government policies encourage PV demand?*	• Supply-related policies encourage or require utilities to invest in PV through Renewable Portfolio Standards (RPS) and cap&trade/allowance-allocation regulations, which help to create a market for green tags. • Demand-related policies encourage customers to purchase PV through incentives such as tax credits, subsidies/buy-downs, low-interest loans, accelerated depreciation, net metering, etc. • The long-term uncertainty surrounding government policies and/or lack of adequate funding often leads to annual variability in PV demand for grid-connected applications.
Customer Behavior *Are there behavioral factors that favor the appeal of PV?*	• 'Green consciousness' due to environmental concerns has been a key driver for early adopters. • Increasingly, PV contributes towards enhancement of public image for commercial customers and has a status symbol for residential customers. • PV also appeals to customers who seek independence in power supply, reduction in risk due to the variability in electricity prices, and peak power reductions.

…of which PV economics, which is a function of system price and government policies, is the most important factor.

1) LCOE = Levelized cost of electricity

Measures of payback period and return on investment are the metrics most commonly used to evaluate an investment in PV.

Relevant Economic Metrics[1]	
Residential Segment	• The most common factor considered for residential applications is the ***simple payback period***. • Retrofit applications are implemented by home owners while new construction applications are mainly implemented by home developers and influenced by architects. • In the case of new construction applications, home developers will typically not consider installing PV systems if it costs more than 1-2% of the cost of the house.
Commercial Segment	• Commercial customers tend to take a longer term perspective in considering an investment, and hence take into account a life cycle cost approach. However, budget constraints may adversely impact the decision to invest in PV even if it is a worthwhile investment. • The most common metric used is a measure of ***return on investment***, such as the ***internal rate of return.*** Some customers also consider ***simple payback period.***

We used payback to estimate market potential[2].

1) Source: Discussions with Howard Wenger of PowerLight, and interviews by NCI staff with homebuilders/developers/end-users.
2) For the commercial segment, we did not use a return on investment criteria to calculate the market potential because of a lack of relevant market penetration curves that relate likely market penetration to different rates of return.

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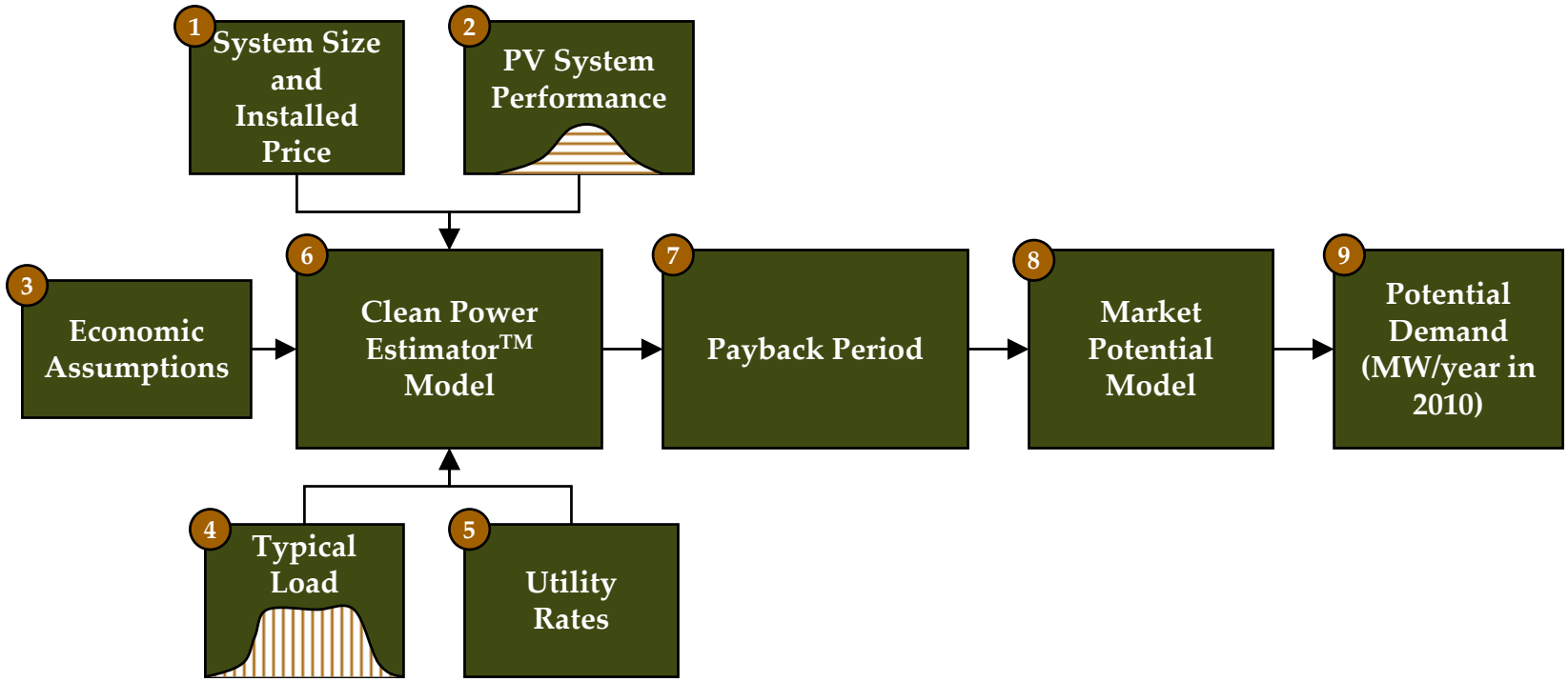
The approach used to assess the market potential for PV in the residential and commercial segments is illustrated below.



A description of each component of the approach is described in the following pages.

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A breakthrough in installed system price is assumed, to reach an average of $2/Wp for large commercial systems[1] by 2010.

1 System Size and Installed Price

Segment[1]	System Size (kWpdc)[2]	Installed System Price ($/Wpdc) in 2010[3]		
		Base-case	Sensitivity cases	Business-as-usual case
Residential	2.5 kWp	$2.50	$ 1.25 $ 3.75	$ 5.30
Commercial: Small/ Medium system size	15.0 kWp	$ 2.20	$ 1.10 $ 3.30	$ 4.65
Commercial: Large system size	100 kWp	$ 2.00	$ 1.00 $ 3.00	$ 4.25

Key Comments

- For a given PV module price, installed system price in $/Wp is higher for smaller systems due to lower economies of scale associated with Balance of System (BOS) equipment cost, fixed installation costs and transaction costs.
- Residential systems cost 17-33%[4] more than large commercial systems. A 25% average cost premium is thus assumed. Small commercial systems were assumed to be higher by 10%, reflecting some lost economies.
- Sensitivity cases reflect ranges around the base-case.
- Business-as-usual (BAU) case reflects the likely price in 2010, with a 3% decline p.a. from the 2003 price of $5.22/Wpdc for large commercial systems to $4.25/Wpdc in 2010. This rate of cost reduction can be achieved with continued government and customer support for PV. No state buy-downs/subsidies are assumed in the 2010 prices shown, but the continued decline in prices in the near term requires continuation of customer incentives in the United States, Europe, and Japan to support plant capacity expansions. [5]
- The selection of the PV system size does not constrain the demand estimation to those sizes only. The PV system size is used only to calculate the payback period. The market estimation is driven primarily by available roof space, payback and market-penetration rates.

1) The commercial segment was classified into two categories – small/ medium and large, to reflect the differences in system size, system price & market potential.
2) Residential system sizes range between 2-3 kWp, though it could be larger. An average of 2.5 kWp was assumed. Commercial system sizes vary much more, ranging between 1 – 500 kWp. The small/medium sizes tend to range between 10-40kWp while the large systems range from 75-500+kWp. The trend is towards larger commercial systems, with many over 500 MWp. 3)2010 dollar; 4) NCI analysis; 5) This is not to suggest that states may not want to offer incentives at this installed cost level. Rather, it is a simplifying assumption that is likely to be the case in many states. For states that might offer customer incentives, this is an assumption that makes the market estimates conservative.

Note: All system size, price and cost data are per Wpdc or nameplate watts, unless otherwise stated.

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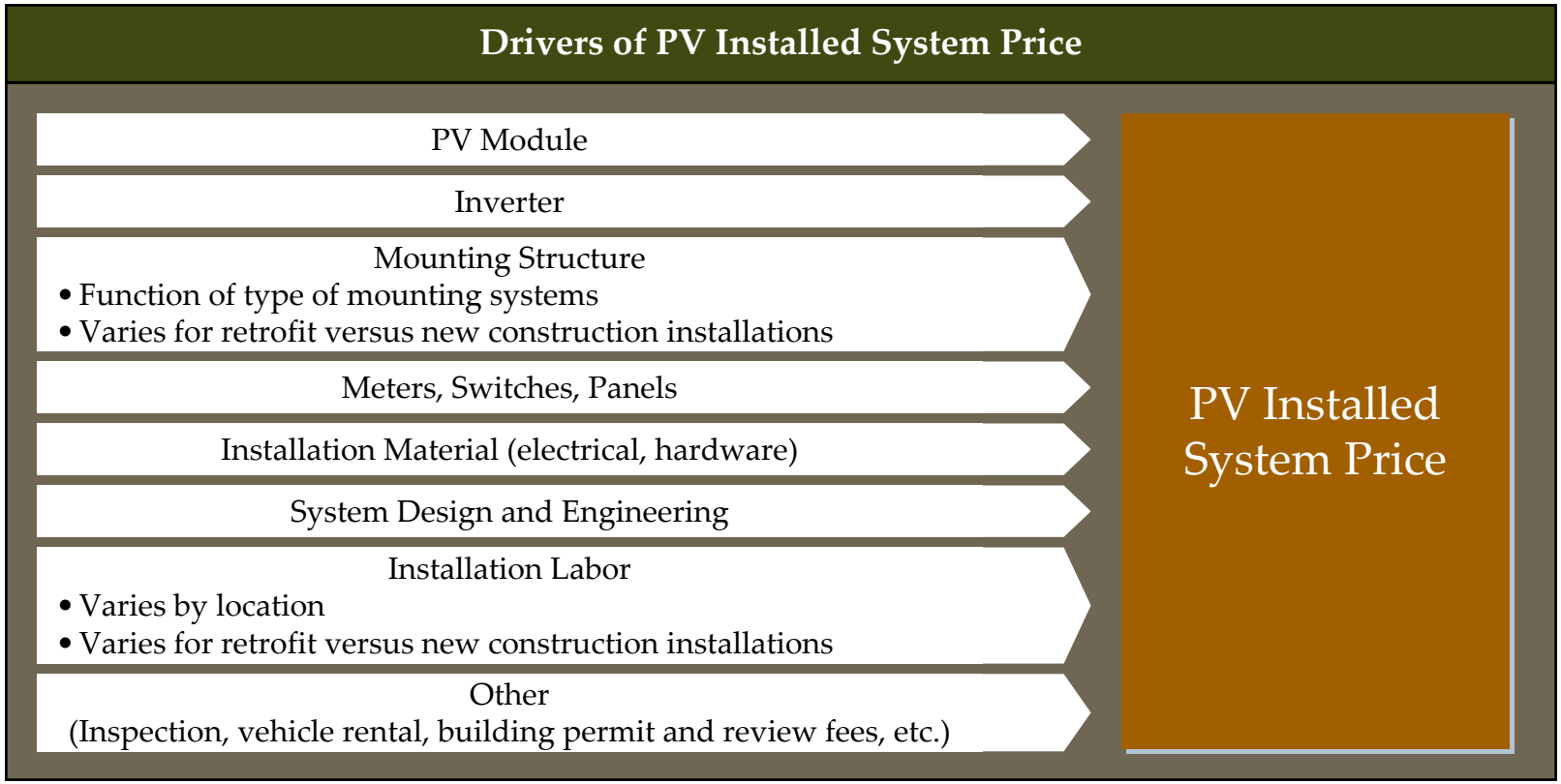
It is worth noting that the installed price for PV systems depends on many factors…



…for this study, we did not take into account differences between retrofit versus new construction, mounting structures, etc.

PV system output assumed: typical installation parameters, x-Si[1] technology, and state capitals for utility rates and insolation levels.

2 PV System Performance

Factors Affecting Performance	Segment			Comments
	Residential	Commercial: Small/Med	Commercial: Large	
PV Technology	Crystalline Silicon			• Crystalline silicon technologies accounted for 92% of module production during 2002. Their share has increased at the expense of thin films during the last decade.
PV System Tilt	18^0 on pitched roof, 0^0 on flat roof	0^0 on flat roof		• Majority of residential homes have pitched roofs, with single family and 2-4 unit homes together accounting for 78% of all residential homes in 2001. • Around 98% of commercial systems are installed with no tilt because of lower installation labor cost and higher roof space utilization[2].
Orientation	South facing			• South facing PV systems provide excellent year-round performance
Tracking System	None assumed			• Tracking helps to increase system output, but also increases cost. Most systems installed do not have tracking systems.
System Location[3]	State Capital			• Location impacts insolation (solar resource) and utility rates for the analysis. The location and utility rates selected were used as representing the state. • California and New York: Two additional locations were selected due to solar resources and/or tiered & wide range of tariff rates.

1) X-Si is crystalline silicon technology, which comprises mono and poly crystalline silicon
2) Systems with 10° tilt need around 30% more roof space. Source: Interview with PowerLight.
3) The locations by state are provided in the Appendix.

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Key economic assumptions include: net metering, RECs with a $.015/kWh value, and minimal Federal incentives.

3 **Economic Assumptions**

Factor[1]	Segment			Comments
	Residential	Commercial: Small/Med	Commercial: Large	
System Life	30 years			• Typical for crystalline silicon technologies.
O&M Cost ($/kW/year)	-	11	11	• O&M cost is not material for residential. Commercial building O&M is mostly labor and is assumed to increase at 2.5% p.a. during project life.
Replacement Expenditure	-			• Inverters will be replaced once during the project life. Cost is negligible and was therefore not incorporated into the analysis.
State Incentives	0			• Purpose of study is to analyze market potential without the support of significant incentives. Only minimal incentives at the federal level is assumed.
Federal Tax Credits (%)	15	10	10	• The 15% residential Tax Credit is being proposed. Commercial Investment Tax Credit has been available for several years and is very likely to continue.
Accelerated Depreciation	-	MACRS 5 year class		• Federal incentive that currently exists and is likely to continue. Applicable only to commercial customers.
REC[2] Value ($/kWh)	0.015			• Assumption reflects the federal cap of $15/MWh. Current PV REC values are much higher, reflecting limited availability in trading system. Value of REC is indexed to inflation at 2.0% p.a. during project life.
Net Metering	Exists			• Assumes no net annual generation by the PV system
Discount Rate	7%	8.5%		• Based on NCI analysis, recommendations by the Department of Energy and Berkeley Lab for air conditioners. • Assumed PV purchase financed by loan/mortgage for residential customers.

1) All data are in 2010 dollars 2) REC = Renewable Energy Certificate

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We assumed the average monthly consumption by segment in each state to be the same as that in 2001.

4 Typical Load

Typical Customer Load By Segment, By State[1] (kWh/year, 2001)

State	Residential	Commercial: Small/Med	Commercial: Large
Region: Midwest - East North Central			
Illinois	8,711	87,455	7,394,237
Indiana	11,427	86,112	2,344,113
Michigan	7,788	74,755	2,480,151
Ohio	9,826	70,344	70,344
Wisconsin	8,634	65,732	4,673,847
Region: NorthEast - Middle Atlantic			
New Jersey	7,934	81,329	938,889
New York	6,532	65,638	2,472,830
Pennsylvania	9,081	54,710	1,384,796
Region:			
…			
…			
…			
…			
…			

Key Comments

- A key aspect of determining the economic attractiveness of PV is comparing its output in kWh/year to a typical customer's load (and hence utility bill).
- The typical load is assumed to be the average consumption in kWh/year, as provided by the EIA.
  - Residential: the average residential consumption is considered.
  - Small/ medium commercial: the average commercial sector consumption was used.
  - Large commercial: the average industrial sector consumption was used.
- A typical load profile is mapped on the typical PV load[2] – this enables comparing the load profile with PV output.
- Net metering was assumed, but with no net annual generation value (i.e. if PV system has a net annual export of output to the grid, the customer does not get additional compensation).
- It is assumed that the average load per customer does not change.
- The use of the average consumption in states with tiered rate structures probably understates the potential for PV for these states, because in these states, customers with high consumption and hence high utility rates would see higher returns on PV investment.

1) Source: EIA, US Average Monthly Bill by Sector, Census Division and State, 2001. Details for all states and segments provided in the Appendix.
2) The typical load profile is as provided by the Clean-Power Estimator™ Database, which is described later in the report.

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Utility rates are expected to increase at 3.7% per annum from 2003 through 2010, while the rate structure is assumed to remain the same.

5

Utility Rates

Utilities Whose Rates are Assumed[1]

State	Location	Utility
Midwest - East North Central		
Illinois	Chicago	Commonwealth Edison Co.
Indiana	Indianapolis	Indianapolis Power and Light
Michigan	Detroit	Detroit Edison
Ohio	Cleveland	FirstEnergy Corp (The Illuminating Company)
Wisconsin	Milwaukee	We Energies (Wisconsin Electric)
Midwest - West North Central		
Iowa	Cedar Rapids	IES Utilities
Kansas	Topeka	Kansas Power and Light (Western Resources)
Minnesota	St. Paul	Xcel Energy (Northern States Power)
Missouri	Jefferson City	AmerenUE - Missouri (Union Electric)
Nebraska	Lincoln	Lincoln Electric
North Dakota	Bismarck	Montana-Dakota Utilities
South Dakota	Sioux Falls	Xcel Energy (Northern States Power)
NorthEast - Middle Atlantic		
....		
....		
....		
....		
....		

Key Comments

- The utility rates used are those of the largest utility in the locations selected, which as mentioned earlier is the state capital, as well as two additional locations in California and New York. The actual rate structures of the utilities selected were used in the analysis, rather than an average rate structure for the country.
- For the analysis, assumptions need to be made about the utility rates during the project life, which is from 2010 (the year in which low cost systems will be available) till 2040, given that PV systems have an operating life of 30 years.
  - It is assumed that the rate *structure* during the period of analysis remains the same as in 2003.
  - The *rates* increase at an average rate of 3.7% per annum from 2003 till 2010, and at 2% per annum thereafter for the project life[2].
- It must be noted that there may be utilities other than those selected for this study whose utility rates are higher, which could result in higher returns for a PV investment.

1) Full list of utilities is provided in the Appendix.
2) NCI analysis, based on forecast regarding electricity prices (as provided in the EIA's Annual Energy Outlook 2003) and inflation assumptions.

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The Clean Power Estimator™ model conducts the PV output and payback analysis by state and segment.

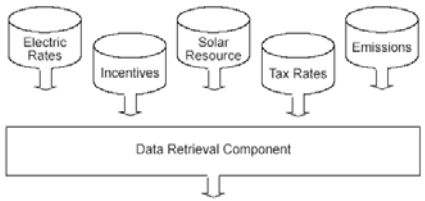
6

Clean Power Estimator™ Model

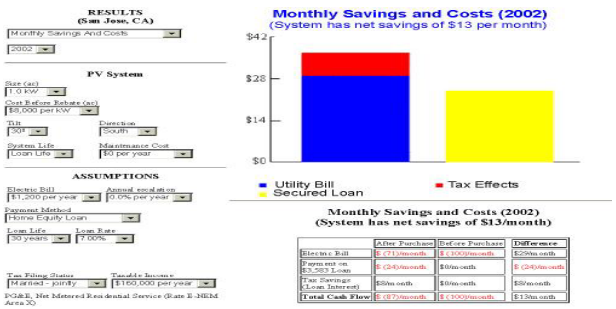
Model Overview[1]

The three key components of the model…

The Data component of the model…



An illustration of one of the model outputs…



Key Comments

- The Estimator is a suite of Internet based applications designed to help consumers evaluate the cost effectiveness of clean energy systems, including PV.
- It provides an estimate of the costs and benefits of a system for residential or commercial customers. It takes into account system size, system installation, system price, financial assumptions, utility rates and solar resources across locations.
- There are three critical components of the Estimator: Data, Analysis and Applications.
- With the Data component, amongst other information, the Estimator has data on the solar resource for 237 locations and includes the utility rates for more than 400 locations (with over 1500 rate schedules, covering residential and commercial customers).
- It produces several outputs. We have used the payback calculation in our analysis to estimate the market potential for PV.

1) Brief description provided in the Appendix. Complete model documentation is available at http://www.clean-power.com

The weighted[1] average payback in 2010 is 9-12 years for a system price of $2.00-2.50/Wpdc, and 13-19 years for a price of $4.25-$5.30/Wpdc.

7

Payback Period[2]

Payback : U.S.

Residential

System size = 2.5 kW

System Price ($/Wpdc)	Payback (years)		
	Wt. Av.	Max	Min
$1.25	7	11	4
$2.50	12	18	7
$3.75	15	22	10
$5.30	19	27	13

Commercial - Small/Medium

System size = 15 kW

System Price ($/Wpdc)	Payback (years)		
	Wt. Av.	Max	Min
$1.10	6	9	3
$2.20	9	13	5
$3.30	11	16	7
$4.65	13	17	9

Commercial - Large

System size = 100 kW

System Price ($/Wpdc)	Payback (years)		
	Wt. Av.	Max	Min
$1.00	6	11	3
$2.00	9	15	6
$3.00	11	17	8
$4.25	13	19	9

Key Comments

- Payback is calculated taking into account net system price and first year savings.
- The net system price assumes a federal Tax Credit of 15% for residential systems (which is proposed) and 10% Investment Tax Credit for commercial (which currently exists). In addition, the federal accelerated depreciation incentive provided to commercial customers is considered.
- Savings during the first year take into account after-tax utility bill savings, first year loan interest tax savings, and the value of Renewable Energy Certificate (RECs) at $0.015/kWh, less first year O&M costs.
- Payback is calculated by segment, by state for each installed system price scenario.
- An installed system price 50% less than the business-as-usual price (i.e. $2.00-2.50/Wpdc instead of $4.25-5.30/Wpdc) leads to a 40% reduction in payback for residential customers (from 19 years to 12 years) and to ~30% reduction for commercial customers (from 13 years to 9 years)
- At low system prices, payback in some states can be as low as 3-4 years. However, there are some states where the payback will still be 9-11 years.
- Payback is not directly proportional to system price because the value of loan interest tax savings are considered – thus, a 50% reduction in system price does not correspond to a 50% reduction in payback, because the first year savings change as well due to tax deductibility of loan interest.

1) Weighting is done by number of customers by state, by segment. Data source: EIA, 2001 data. Data on number of customers is provided in the Appendix.
2) Data on payback by state and segment for different installed system price is provided in the Appendix.

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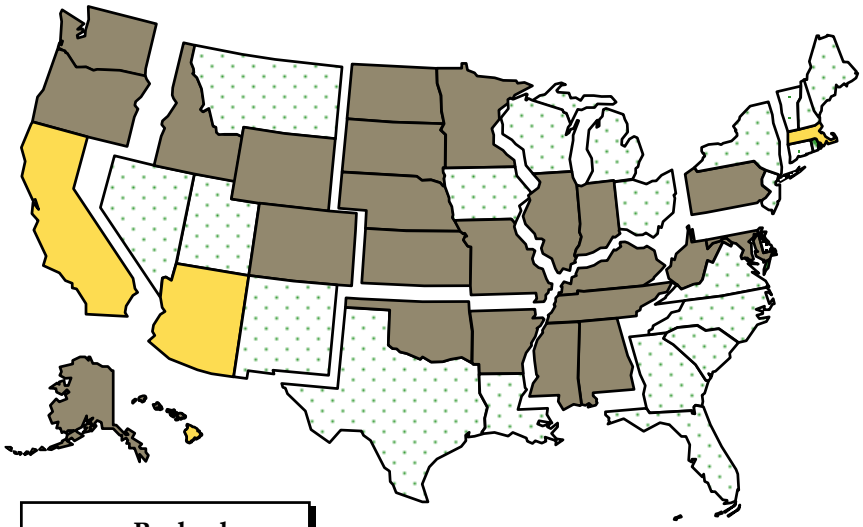
At $2.50/Wpdc for residential systems in 2010, payback for some states is 6-10 years, while under the BAU case it is >10 years for all states.

Payback in 2010, Residential @ $5.30/Wpdc

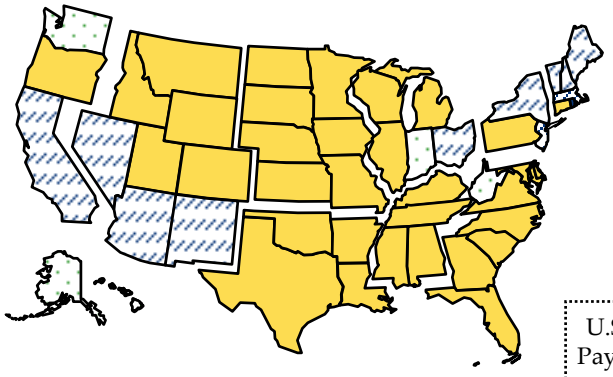


Payback

- > 20 years
- 16 – 20 years
- 11 – 15 years
- 6 –10 years
- <= 5 years

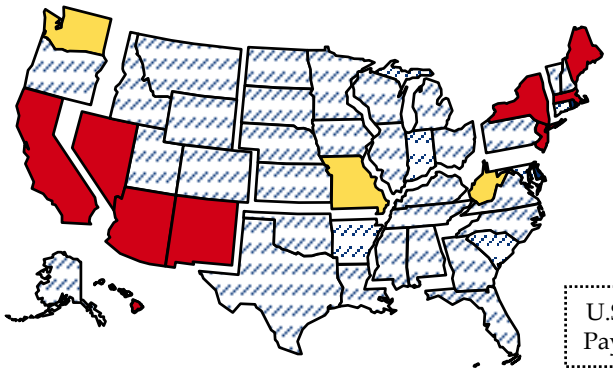
U.S. Wt.[1] Average Payback = **19 years**

Payback in 2010, Residential @ $2.50/Wpdc



U.S. Wt. Average Payback = **12 years**

Payback in 2010, Residential @ $1.25/Wpdc



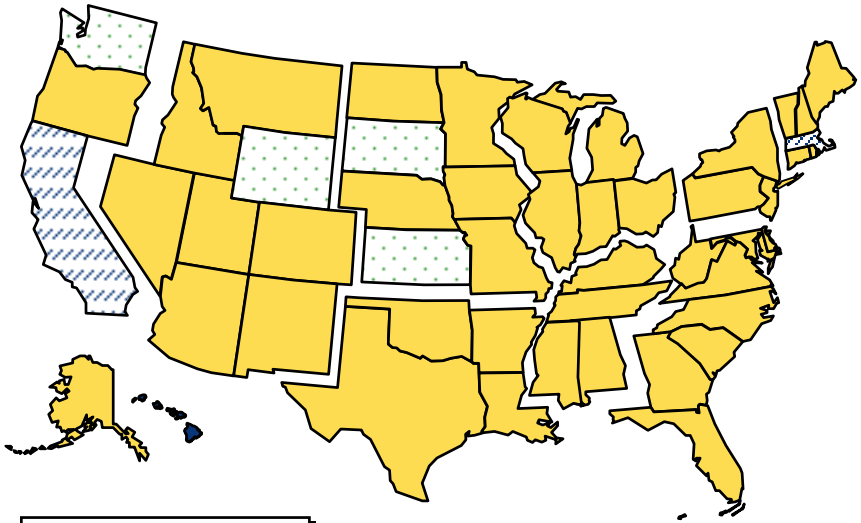
U.S. Wt. Average Payback = **7 years**

At $1.25/Wpdc, most of the U.S. has a payback of <=10 years, with some states at <=5 years.

1) Weighting is done by number of customers by state, by segment.

At $2.20/Wpdc for medium commercial systems in 2010, many states have a payback of 6-10 years, compared to only CA under BAU case.

Payback in 2010, Commercial Small/Med @ $4.65/Wpdc

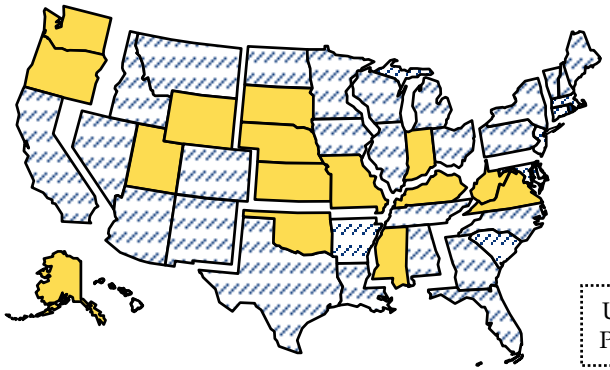


Payback

- > 20 years
- 16 – 20 years
- 11 – 15 years
- 6 –10 years
- <= 5 years

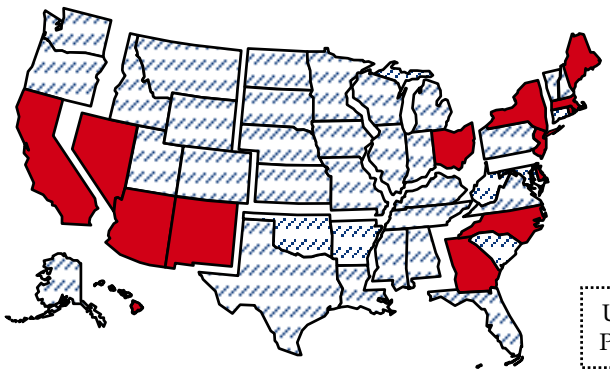
U.S. Wt.[1] Average Payback = **13 years**

Payback in 2010, Commercial Small/Med @ $2.20/Wpdc



U.S. Wt. Average Payback = **9 years**

Payback in 2010, Commercial Small/Med @ $1.10/Wpdc



U.S. Wt. Average Payback = **6 years**

At $1.10/Wpdc, the entire country has a payback of <=10 years, with several states having a payback of <= 5 years.

1) Weighting is done by number of customers by state, by segment.

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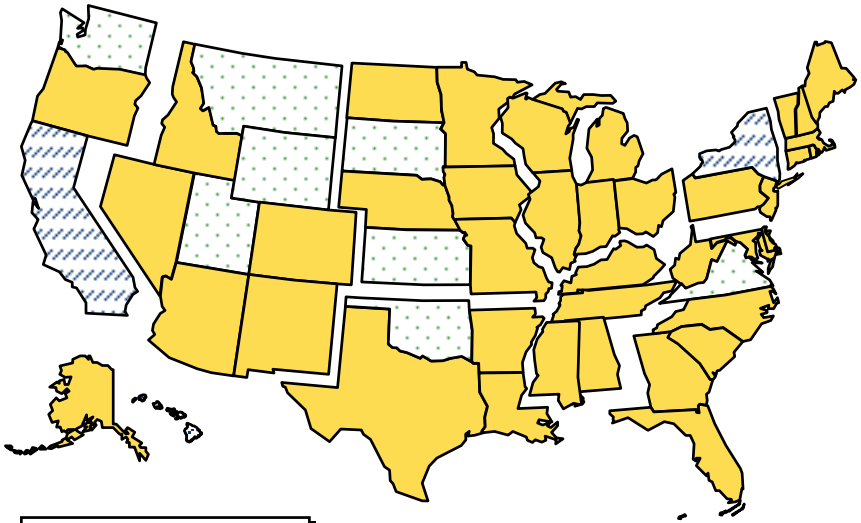
The overall payback trend for large commercial systems is similar to that for medium sized systems, though paybacks are slightly higher…

Payback in 2010, Commercial Large @ $4.25/Wpdc

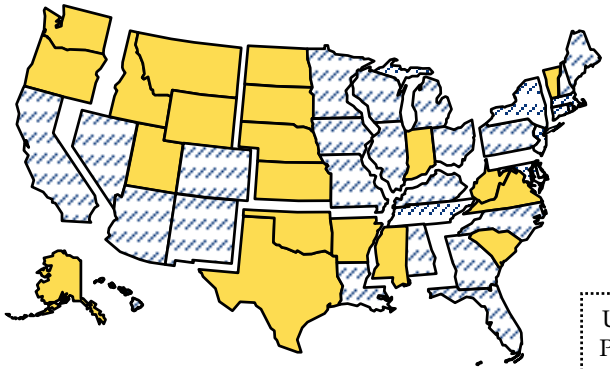


Payback

- > 20 years
- 16 – 20 years
- 11 – 15 years
- 6 –10 years
- <= 5 years

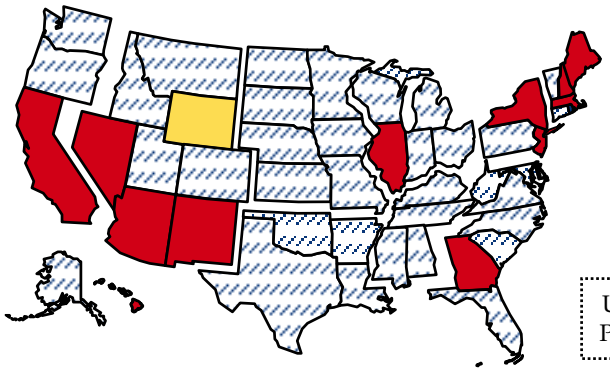
U.S. Wt.[1] Average Payback = **13 years**

Payback in 2010, Commercial Large @ $2.00/Wpdc



U.S. Wt. Average Payback = **9 years**

Payback in 2010, Commercial Large @ $1.00/Wpdc



U.S. Wt. Average Payback = **6 years**

…reflecting the lower utility rates for large commercial customers.

1) Weighting is done by number of customers by state, by segment.

The logic and main components in the model to estimate the potential grid-connected demand for PV in 2010 is as follows:

8 **Market Potential Model**

Key Components of Market Potential Model

8.1 Roof Space Available for PV in 2025 (Mln. sq. ft) **x** 8.2 PV Power Density in 2025 (Wp/sq. ft) **=** 8.3 Technical Market in 2025 (MWp)

x

8.4 Cumulative Market Penetration in 2025 (%) **=** 8.5 Potential Cumulative Market in 2025 (MWp)

x

8.6 Technology Adoption S-Curve from 2003-2025 (%) **=** 8.7 Potential Annual Demand in 2010 (MWp)

Note:

- The objective of this project is to estimate the potential demand in 2010.
- Market penetration curves provide the cumulative market penetration ~15 years after a product has been introduced. These curves are thus used to calculate the cumulative market in 2025.
- The likely demand in 2010 is then calculated using an S-curve, which predicts the rate of technology adoption.

Total roof space available for PV in 2025 is estimated at 84.5 billion ft², compared to 62.4 billion ft² in 2003, with a residential share at 53%.

8.1 Roof Space Available for PV in 2025 (Mln. sq. ft)

Roof Space: U.S. [1]

Roof Area Available for PV Systems		2003	2010	2025
Total, by segment				
Residential	Mln. Sq. Ft.	33,969	37,616	45,005
Commercial - Small/Medium	Mln. Sq. Ft.	24,463	27,302	33,982
Commercial - Large	Mln. Sq. Ft.	4,003	4,492	5,556
Total	Mln. Sq. Ft.	62,436	69,409	84,544
As % of total roof area				
Residential	%	22%	22%	22%
Commercial	%	65%	65%	65%
As % of total floor area				
Residential	%	16%	16%	16%
Commercial	%	60%	60%	60%

Roof Available for PV in 2025	Residential		Commercial - (Small/Medium & Large)		Total	
	Mln Sq. Ft.	% share	Mln Sq. Ft.	% share	Mln Sq. Ft.	% share
Midwest						
East North Central	6,659	15%	5,244	13%	11,903	**14%**
West North Central	3,205	7%	2,646	7%	5,851	**7%**
NorthEast						
Middle Atlantic	4,202	9%	3,117	8%	7,319	**9%**
New England	1,710	4%	1,430	4%	3,140	**4%**
South						
East South central	3,642	8%	3,650	9%	7,293	**9%**
South Atlantic	9,004	20%	8,394	21%	17,397	**21%**
West South Central	6,309	14%	4,492	11%	10,801	**13%**
West						
Mountain	3,065	7%	3,609	9%	6,674	**8%**
Pacific	7,210	16%	6,957	18%	14,166	**17%**
Total	**45,005**	100%	**39,538**	100%	**84,544**	**100%**
% share of total	**53%**		**47%**		**100%**	

Key Comments

- Total roof space available for PV systems is defined as:
  Total roof space available for PV =Total roof space of buildings
  less
  Roof unavailable due to solar access issues
- The total roof space available for PV due to solar access issues differs by type of roof, and is as follows:
  Pitched roof = 18%[2]
  Flat roof = 65%[2]
- The total roof space available by segment is estimated as follows:

	Commercial[2]	Residential[2]
Total roof space by type		
- % pitched roof area	0%	92%
- % flat roof area	100%	8%
Total available roof space		
- % of total roof space	65%	22%

Note : Amongst residential buildings, it is assumed that single family homes and 2-4 unit apartments have pitched roofs while 5+ unit apartments and mobile homes have flat roofs.

1) The methodology and data used to calculate available roof space by state and segment is provided in the Appendix.
2) Details provided in the Appendix.

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Space available for PV installations depends on roof type, orientation, shading and other factors, collectively called 'solar access' issues.

Roof Type

The roof type determines the potential tilt of PV systems that can be installed.

There are two primary roof types:
- Flat
- Pitched

Structural Adequacy

PV systems add load to roofs. As such, the structural adequacy of roofs and building codes needs to be taken into consideration, though it is typically not an issue.

Material Compatibility

Roof building materials should support PV system installations, and most do support PV installations. There may be cases where PV may not be aesthetically compatible, but this issue is not considered.

Shading

Shading reduces the output of PV systems and hence reduces eligible roof area available. Shading occurs from:
- Trees
- HVAC, other equipment
- Vent stacks, chimneys, other roof structures

Orientation

PV systems are most productive when oriented from southeast clockwise around to west.

The orientation of pitched roofs determines the eligible roof space.

The impact of the above issues on roof space available for PV systems is discussed in the Appendix.

Power density of PV *systems* is estimated at 10.2 and 12.3 Wp/sq. ft. in 2010 and 2025 respectively, compared to 8.7 Wp/sq. ft. in 2003.

8.2 PV Power Density in 2025 (Wp/sq. ft)

Key Assumptions

- Crystalline silicon (x-Si) technology, which comprises mono crystalline and poly crystalline silicon is the most efficient PV technology and also the most dominant in the market, with a 92% share of PV module production in 2002.
- During 2003, the weighted average power density of crystalline silicon *modules* was 10.8 Wp/sq. ft. PV system installations require an area approximately 1.25 times the area of PV modules, to provide space between modules, wiring, access to modules etc. The *system* power density is thus lower than the module power density.
- Assuming the same distribution in production between mono and poly crystalline silicon, it is estimated that due to efficiency improvements, the PV module power density in 2010 will be around 12.8 Wp/sq. ft, or an increase of 2.4% per annum, resulting in a PV system density of 10.2 Wp/sq. ft.
- Assuming that due to scientific and engineering constraints the rate of improvement in efficiency is slower by half beyond 2010, the power density of PV modules in 2025 is estimated at 15.3 Wp/dc, or a PV system power density of 12.3 Wp/sq. ft.

Technology	*% share in x-Si production*	*Module power density (Wp/sq. ft).*	*System power density (Wp/sq. ft.)*		
			2003	*2010*	*2025*
Mono crystalline	41%	12.2			
Poly-crystalline	59%	9.9			
Weighted average		10.8	8.7	10.2	12.3

Source: NCI analysis

The technical market for grid-connected PV in 2025 is estimated at ~1,000 GWp, an average increase of 3% p.a. from ~ 540 GWp in 2003…

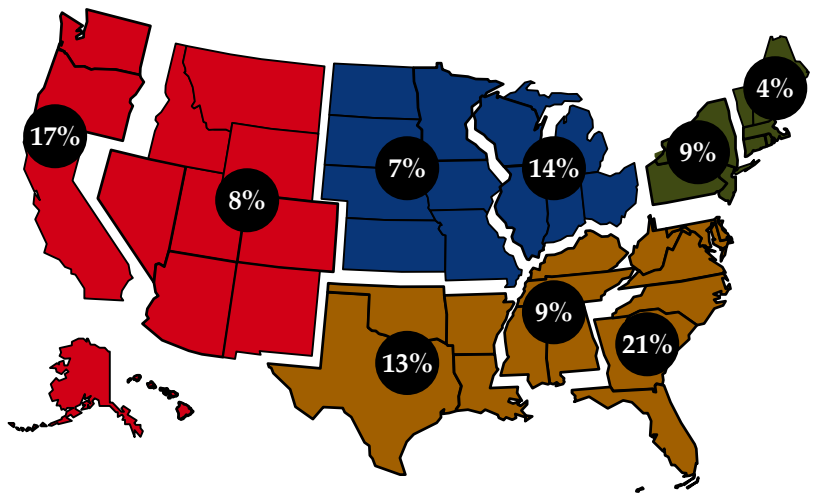
8.3 Technical Market in 2025 (MWp)

Technical Market in U.S. [1]

Technical Ultimate Potential (MWp)	2025		2003	
	MWp	% share	MWp	% share
Residential	552,307	53%	294,855	54%
Commercial - Small/ Medium	417,032	40%	212,343	39%
Commercial - Large	68,181	7%	34,750	6%
Total	**1,037,519**	**100%**	**541,948**	**100%**

- The technical potential is almost equally split between residential and commercial segments.
- Region wise, West-Pacific and South-Atlantic account for the highest technical potential in 2025 at 17% and 21% respectively, driven by roof space available for PV.

Technical Market By Census Region: 2025 % share of total



…driven by growth in building stock and an increase in power density of PV systems.

1) State-wise details of technical potential in 2025 provided in the Appendix.

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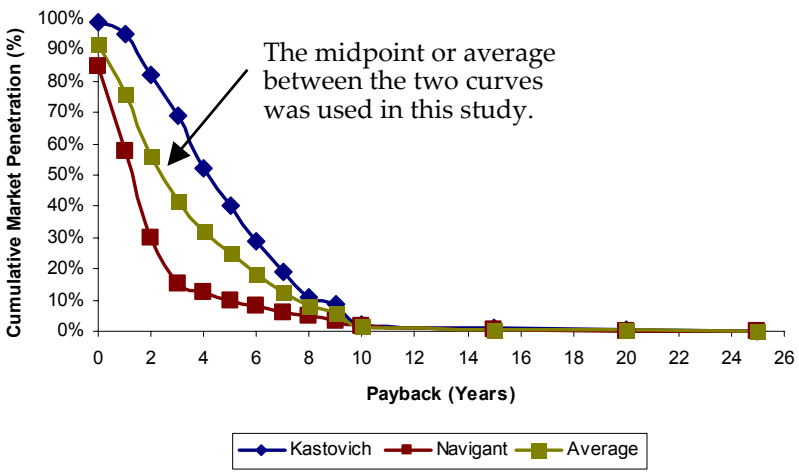
This analysis did not assume a higher penetration rate (e.g., that experienced by hi-tech products) for the following reasons.

8.4 Cumulative Market Penetration in 2025 (%)

Payback vs. Cumulative Market Penetration Curves[1]



Key Comments

- The curves provide the cumulative market penetration 10-20 years after product introduction, as a function of payback.
- The Kastovich[1] (for replacement market) and Navigant[2] curves are considered to be the most appropriate curves to calculate the market potential for PV, because they reflect investments in electric products, with a focus on the replacement market, which is analogous to the retrofit market (new construction accounts for less than 2% of building stock).
- Rapid penetration rates of hi-tech products is not considered to be comparable to PV because of the following:
  - Comparatively high upfront cost and payback of > 5 years associated with PV, even with low system price
  - 'Green' attribute does not drive the main market
  - The 'network' effect and high adoption rates of products such as computers and cell phones where the value of being a customer increases as the network grows is not relevant to PV
  - Investment of significant time and resources is needed to develop the manufacturing and marketing infrastructure required to serve a market of more than 100 MWp/year[3].
- The Kastovich curve is more aggressive than the Navigant curve: a midpoint between the two was thus considered in the analysis.

1) Kastovich, J.C., Lawrence, R.R., Hoffman, R.R., and Pavlak, C., 1982, "Advanced Electric Heat Pump Market and Business Analysis.". The curves apply simple payback as the criteria, and were developed for the residential market.

2) Proprietary data belonging to Navigant Consulting. Developed by the Navigant team while at Arthur D. Little, based on HVAC penetration experience for the Building Equipment Division, Office of Building Technologies, U.S. Department of Energy (DoE) in 1995. The Navigant curve is used by the DoE in its evaluation of energy efficiency and distributed energy technologies, which was confirmed in an interview with Steve Wade in January 2004.

3) Sales of PV in the U.S. during 2003 is estimated at 70 MWp.

The potential cumulative grid-connected PV market in 2025 is estimated at 47 GWp, at a PV system price of $2.00-2.50/Wpdc in 2010.

8.5 Potential Cumulative Market in 2025 (MWp)

Potential Cumulative Market in 2025

Residential

System size =	2.5 kWp	
Technical Market (MWp) =	552,307	
System Price ($/Wpdc)	**MWp**	**% mkt share**
$1.25	86,641	15.69%
$2.50	15,538	2.81%
$3.75	4,793	0.87%
$5.30	2,593	0.47%

Commercial

Commercial - Small/Medium and Large Total		
System size =	15 kWp, 100 kWp	
Technical Market (MWp) =	485,213	
System Price ($/Wpdc)	**MWp**	**% mkt share**
$ 1.00 - 1.10	96,314	19.85%
$ 2.00 - 2.20	31,487	6.49%
$ 3.00 - 3.30	13,816	2.85%
$ 4.25 - 4.65	8,205	1.69%

Grid Connected - Total

Technical Market (MWp) =	1,037,519	
System price ($/Wpdc)	**MWp**	**% mkt share**
$ 1.00 - 1.25	182,955	17.63%
$ 2.00 - 2.50	47,025	4.53%
$ 3.00 - 3.75	18,609	1.79%
$ 4.25 - 5.30	10,798	1.04%

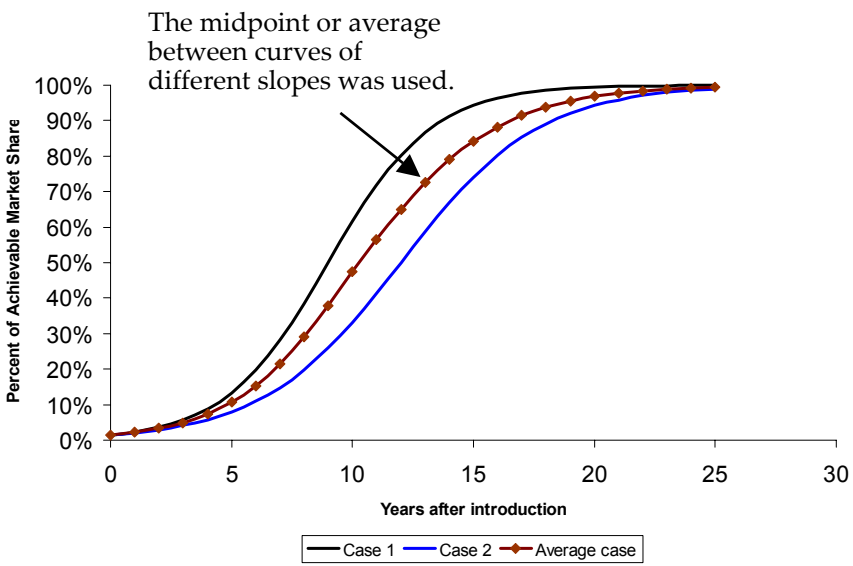
Key Comments

- The potential cumulative market potential is calculated on a state-by-state basis and summed to arrive at the total for the U.S.
- As can be seen from the table on the left, if a PV system in the $2.00-2.50/Wpdc is introduced in 2010, a cumulative of 47 GWp could be achieved by 2025, assuming investment is made in manufacturing and marketing infrastructure to support this level of penetration, with appropriate market development efforts (awareness, training, interconnection, net metering in all states, etc).
- A system price of $1.00-1.25/Wpdc dramatically increases the potential cumulative market, because as shown earlier in the report, the payback becomes fairly attractive.
- The importance of appropriate market development efforts cannot be underestimated. To put the projected cumulative market potential in 2025 in perspective, it must be noted that the estimated cumulative grid connected PV in the U.S. is currently ~200 MWp.

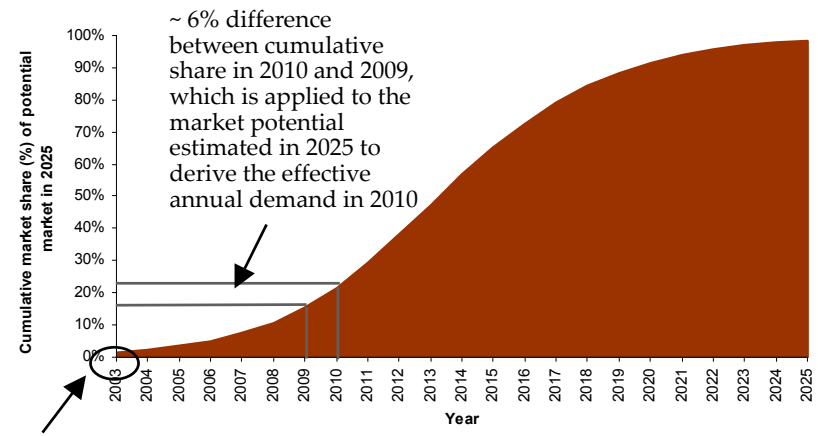
The typical technology adoption S-curve is used to calculate back the market penetration for the year 2010 from 2025.

8.6 Technology Adoption S-Curve from 2003-2025 (%)

Typical S-Curve



S-Curve to Calculate Potential Demand in 2010



Cumulative market penetration in 2003 is estimated at 1.4% of the likely cumulative market in 2025 under a BAU case.

The potential grid-connected annual demand for PV in 2010 at a system price of $2.00-2.50/Wpdc is estimated at 2.9 GWp, valued at ~$6.6 billion.

8.7 Potential Annual Demand in 2010 (MWp)

Potential Annual Demand in 2010

Residential

System size = 2.5 kW
Technical Market (MWp) = 385,790

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$1.25	5,344	1.39%	6.7
$2.50	958	0.25%	2.4
$3.75	296	0.08%	1.1
$5.30	160	0.04%	0.8

Commercial

Commercial - Small/Medium and Large Total
System size = 15 kWp, 100 kWp
Technical Market (MW) = 326,074

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$ 1.00 - 1.10	5,941	1.82%	6.5
$ 2.00 - 2.20	1,942	0.60%	4.2
$ 3.00 - 3.30	852	0.26%	2.8
$ 4.25 - 4.65	506	0.16%	2.3

Grid Connected - Total

Technical Market (MW) = 711,864

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$ 1.00 - 1.25	11,285	1.59%	13.1
$ 2.00 - 2.50	2,901	0.41%	6.6
$ 3.00 - 3.75	1,148	0.16%	3.9
$ 4.25 - 5.30	666	0.09%	3.2

Key Comments

- The demand for PV in the year 2010 is calculated by applying the S-curve discussed earlier to the likely cumulative market potential in 2025, and is estimated at around 6% of the same.
- As can be seen, this demand estimation is highly sensitive to the slope of the S-curve. Moving slightly above or below the S-curve could decrease or increase the 6% share to 3% or 9%.
- The precise position of the PV industry on the S-curve in 2010 is hard to predict, as it depends on many factors including technological developments, investment in manufacturing capacity, market development, consumer behavior and government policies.
- Based on the analysis conducted, it is estimated that the potential demand in 2010 at a system price of $2.00-2.50/Wp is around 2.9GWp[1], assuming the industry can provide the capacity and marketing infrastructure and would have invested in market development prior to 2010 to make it happen. This is orders of magnitude higher than the 2003 estimated demand of 70MWp, valued at around $750-800 million, which may be considered to be constrained due to inadequacy of government incentives (across all states) and funds.[2]

[1]Discussions with a major PV manufacturer indicate that the total (grid-connected and off-grid) potential PV demand in the U.S at a system price of ~$2.00 (which is expected to happen much later than 2010) is around 3GWp. [2]Note that the business-as-usual case projects almost a ten-fold increase in the PV market by 2010, resulting in an annual value of $3.2 billion.

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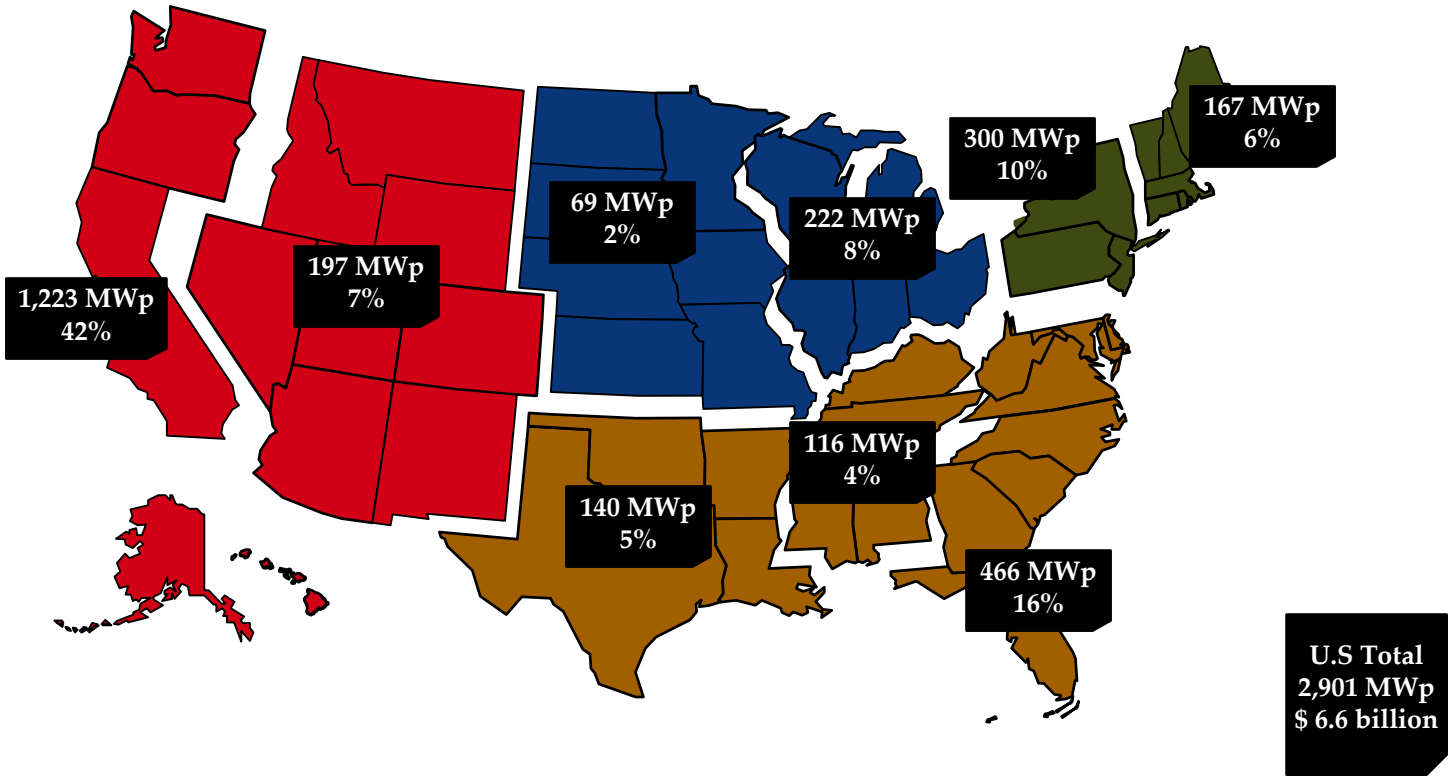
At a system price of $2.00-2.50/Wpdc, the Pacific and Mid Atlantic regions together account for 52% of the potential annual demand in 2010[1].

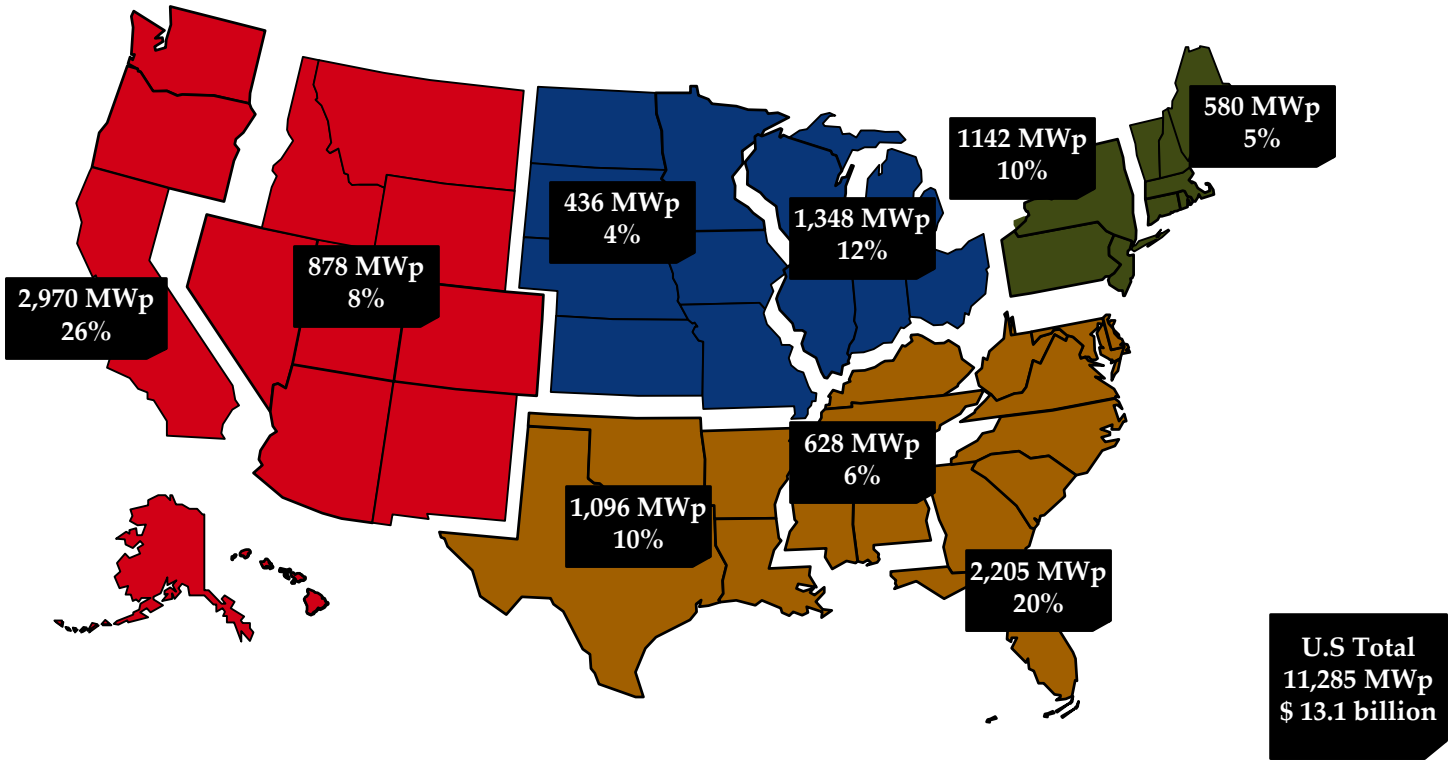
Potential Grid Connected Demand in 2010 By Census Region: MWp/year and % Share
Installed System Price: $2.00 – 2.50/Wpdc



1) Potential demand in 2010 by segment (residential, commercial, total) by state and different system price scenarios is provided in the Appendix.

At a system price of $1.00-1.25/Wpdc, the potential in the Midwest and West South Central increases more than in other regions.

Potential Grid Connected Annual Demand in 2010 By Census Region: MWp/year and % Share -- Installed System Price: $1.00 – 1.25/Wpdc

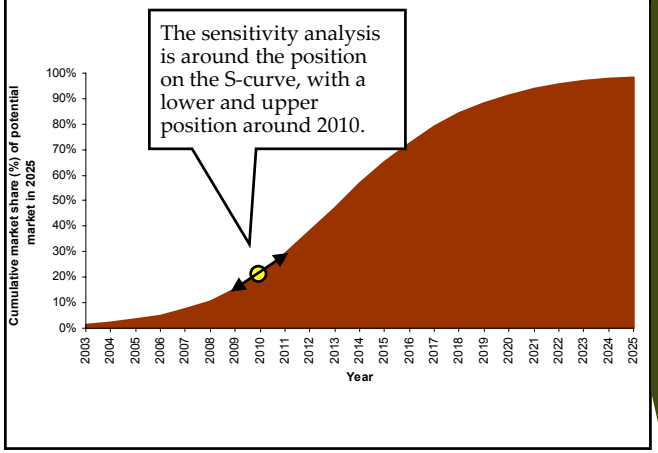


1) Potential demand in 2010 by segment (residential, commercial, total) by state and different system price scenarios is provided in the Appendix.

A sensitivity analysis around the position on the S-curve yields a potential grid-connected demand for PV in 2010 of 2.2–3.6 GWp.

8.7 Potential Annual Demand in 2010 (MWp)

S-Curve to Calculate Potential Demand in 2010



Potential Annual Demand in 2010-Low

Residential

System size =	2.5 kW
Technical Market (MWp) =	385,790

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$1.25	4,053	1.05%	5.1
$2.50	727	0.19%	1.8
$3.75	224	0.06%	0.8
$5.30	121	0.03%	0.6

Commercial

Commercial - Small/Medium and Large Total

System size =	15 kWp, 100 kWp
Technical Market (MW) =	326,074

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$ 1.00 - 1.10	4,506	1.38%	4.9
$ 2.00 - 2.20	1,473	0.45%	3.2
$ 3.00 - 3.30	646	0.20%	2.1
$ 4.25 - 4.65	384	0.12%	1.8

Grid Connected - Total

Technical Market (MW) =	711,864

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$ 1.00 - 1.25	8,559	1.20%	10.0
$ 2.00 - 2.50	2,200	0.31%	5.0
$ 3.00 - 3.75	871	0.12%	2.9
$ 4.25 - 5.30	505	0.07%	2.4

Potential Annual Demand in 2010-High

Residential

System size =	2.5 kW
Technical Market (MWp) =	385,790

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$1.25	6,622	1.72%	8.3
$2.50	1,188	0.31%	3.0
$3.75	366	0.09%	1.4
$5.30	198	0.05%	1.1

Commercial

Commercial - Small/Medium and Large Total

System size =	15 kWp, 100 kWp
Technical Market (MW) =	326,074

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$ 1.00 - 1.10	7,361	2.26%	8.0
$ 2.00 - 2.20	2,407	0.74%	5.2
$ 3.00 - 3.30	1,056	0.32%	3.4
$ 4.25 - 4.65	627	0.19%	2.9

Grid Connected - Total

Technical Market (MW) =	711,864

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$ 1.00 - 1.25	13,983	1.96%	16.3
$ 2.00 - 2.50	3,594	0.50%	8.2
$ 3.00 - 3.75	1,422	0.20%	4.8
$ 4.25 - 5.30	825	0.12%	3.9

1) Discussions with a major PV manufacturer indicate that the total (grid-connected and off-grid) potential PV demand in the U.S at a system price of ~$2.00 (which is expected to happen much later than 2010) is around 3GWp.

2) Market share is relative to the technical market of available roof space.

The potential demand for grid-connected PV in residential and commercial segments could potentially be higher than estimated.

Factors That Could Increase the Demand Estimation for Grid Connected Applications
1. Only roof-top applications were considered. Other applications such as ground mounted PV, car ports, curtain walls, and awnings were ignored. These applications account for a negligible proportion of the market, but is growing.
2. Utility rates could escalate at a rate higher than assumed, which would reduce the payback period for PV systems leading to higher market penetration.
3. The value for Renewable Energy Certificate (RECs) is assumed to be $0.015/kWh in 2010. A higher REC value due to greater demand, particularly for PV RECs, could improve the economics of a PV system and increase demand.
4. The demand estimate is based on the average consumption by customers in the residential and commercial segments. Customers with higher consumption in some states like California have higher utility rates. For these customers, PV economics would be much better than for the "average" customer, which could lead to higher penetration within the high consumption customer category.
5. The economic analysis did not consider any state incentives or policies that would proactively encourage demand.
6. Time-of-use rates that monetize the value of PV coincidence with utility peak loads would improve PV economics.

Source: NCI analysis

Additional analysis of the potential demand for grid-connected PV, as listed below is presented in the Appendix.

- Estimation of the annual demand in 2015, based on assumptions discussed earlier in this report.
- Estimation of the annual demand in 2010, based on the Kastovich market penetration curve and the higher slope S-curve.

Table of Contents

3 » Market Potential for Grid Connected PV

Residential and Commercial Segments

Utilities Segment

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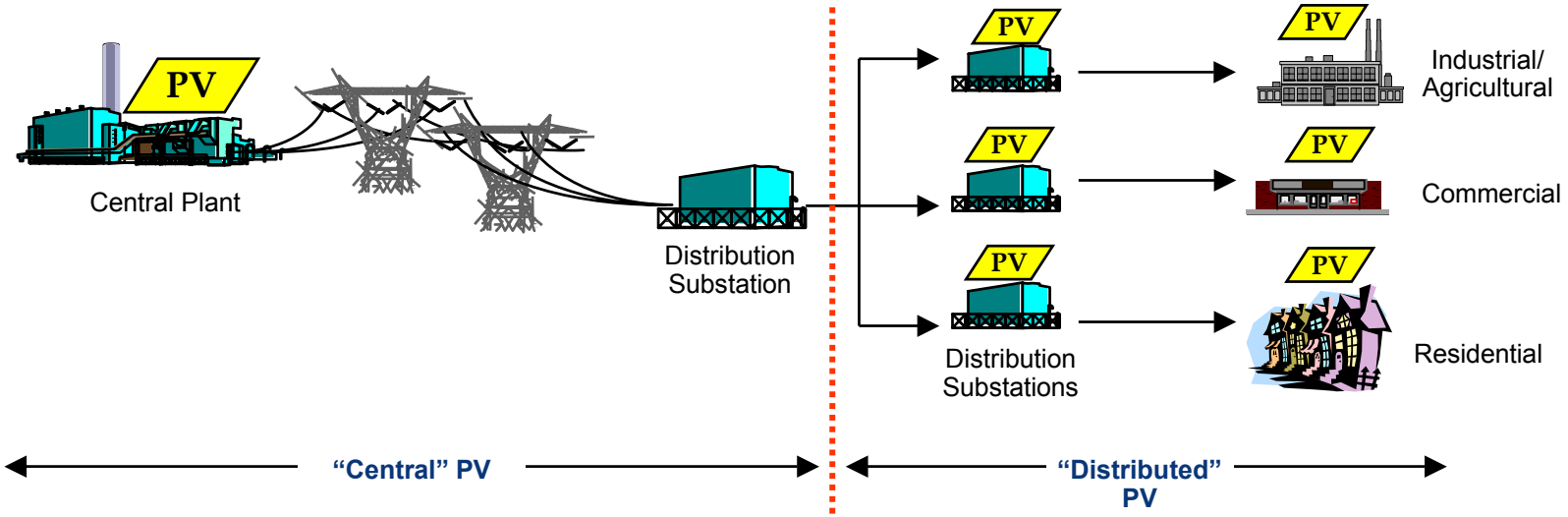
From a utility's perspective, PV can be used at either the central plant location on the power grid or on the distribution part of the system.

Applications of PV on the Power Grid



- "Central" PV plants are of large size (several MW) and connect at the transmission level
- Central PV applications compete against conventional fossil fuel power plants as well as alternative energy sources (wind, biomass, geothermal)

- "Distributed" PV plants are smaller in size and connect to the grid at the substation level or further downstream
- Distributed PV applications compete against other distributed generation technologies such as internal combustion and steam turbines, reciprocating engines, etc.

There are many sources of value from PV, with relatively higher value accruing to "distributed" rather than "central" applications.

Value Source	Comments	Application	
		"Central"	"Distributed"
Energy Value and Capacity Credit	• Energy produced by PV plant can be used either on site or transmitted to loads. • PV output often coincides with peak demand, though this differs by location due to variations in solar resource and load profile • PV is an intermittent energy source, and thus has low dispatchability.	•Low Value -Competes with low cost fossil alternatives -Value from peak shaving -Intermittency	•High value to customer -Competes with high price of retail energy -Value from peak shaving -Saves energy loss •Low value to utility (lost revenues)
T&D Deferral	• PV plants at or near the load reduce the need to upgrade or expand T&D system • The value of deferral is site specific within a utility system, depending on rate of load growth, existing T&D capacity and system condition, etc.	•Low value -Does not provide any deferral value	•Medium-High value -Value accrues to utility whether PV system is owned by it or not -No value if load & system do not have the required profile
Emission Allowance & REC	• PV has practically no emissions • PV is an eligible technology for most RPS requirements • Value of PV meeting RPS mandate depends on whether the mandate has solar set asides, or minimum requirements by class of technology	•Medium – High value -Provides value	•Medium value -Many customers don't need emission allowance or RECs -Can market this value to utilities, but market not fully developed
Other	• Value from fuel price risk mitigation, because PV does not use fuel • Value from intangibles (public relations, "feel good" by community, etc)	•Medium value	•Low – Medium value -Depends on customer profile

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The focus of the demand analysis in the utility segment is for "central" applications.

- Utilities take a life cycle cost-benefit perspective, the analysis of which is impacted by factors such as equipment cost, O&M cost including fuel cost, deferred investment in T&D, fuel price risk mitigation, value of emission allowances, impact on power reliability & quality, etc.
  - In selecting a technology, utilities need to consider all potential technologies.
  - The selection of a technology also needs to take into account utility and site specific conditions and requirements.
- The regulation which most impacts PV demand is RPS requirement. However, most RPS do not mandate PV (except in very few states, through solar set-asides), and hence PV has to compete with other renewable energy sources such as wind and biomass, when utilities seek to comply with RPS regulations.
- PV installation on residential and commercial rooftops provides a utility with more benefits than a central plant, including T&D deferral and saving of energy losses
- Estimating the demand from a utility for PV in "distributed" applications must thus take into account PV installation in the residential and commercial segments within a utility's territory, whether owned by the utility or not in order to avoid double counting.
- The scope of this study does not permit an analysis of the demand of PV from the utility segment taking into account all the above issues.
- This study has evaluated the potential demand from the residential and commercial segments. It is unlikely that there will be an additional demand from the utilities for PV in the distribution part of the system.
- As such, the focus of the analysis in the utility segment is on estimating the demand for "central" applications of PV.

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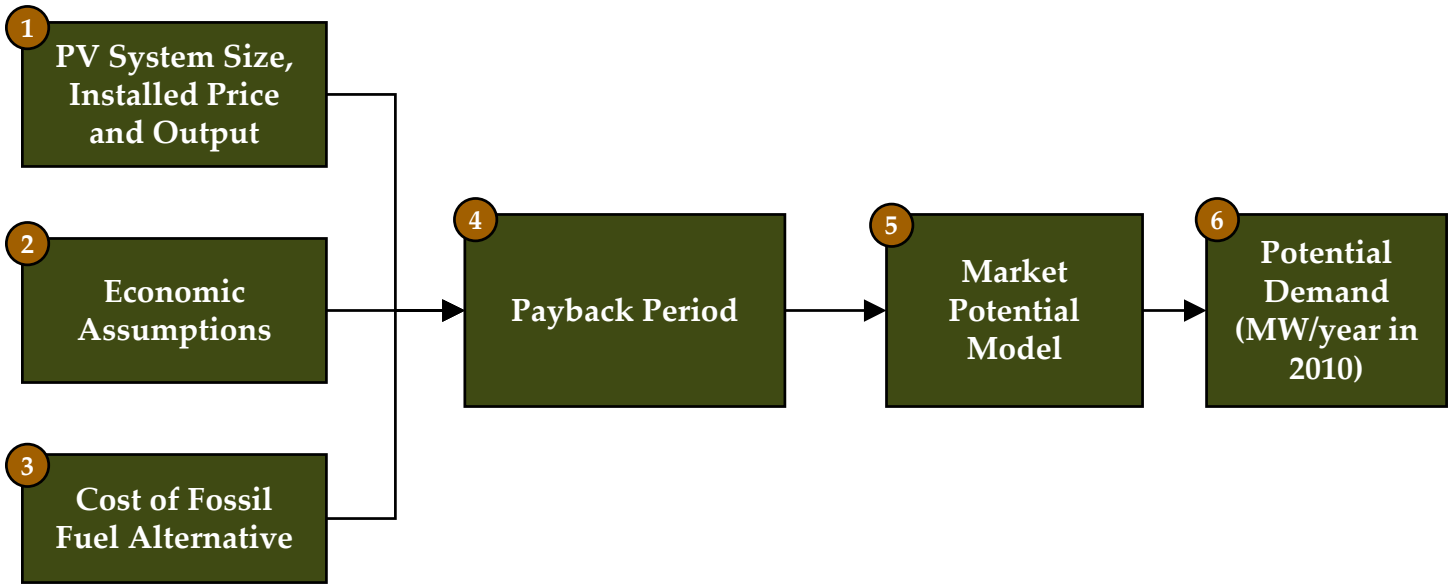
The approach used to analyze the potential demand in the utility segment is illustrated below.



- **The analysis is conducted for only one state, namely California.**
- **A description of each component of the approach is described in the following pages.**

A breakthrough in installed system price is assumed, to reach an average of $2/Wp for large central plant PV systems by 2010.

1 **PV System Size, Installed Price and Output**

Utility Central PV Application		
System Size (kWpdc)		5 MWp
Installed System Price ($/Wpdc) in 2010 (2010 dollars)	Base-case	$ 2.00
	Sensitivity cases	$ 1.00 and $ 3.00
	Business-as-usual case	$ 4.00
System Capacity Factor		20% and 27%

Key Comments

- The large central system sizes currently installed worldwide range between 3.3-5MWp. An average system size of 5MWp is considered reasonable during 2010.
- Central PV systems typically have a tracking system, which while it increases system cost, also results in higher PV system output.
- In addition to the PV cost components for residential and commercial systems, central PV systems also incur land procurement and land development cost. Typically this cost is not large, at 1% of the total project cost.
- In 2004, it is estimated that the installed system cost for a single axis tracking system is around $5.5-7.0/Wpac (or an average of $5.2/Wpdc). This is expected to decline to around $4.00/Wpdc by 2010.
- Two alternative insolation locations in California are assumed, with resulting capacity factors of 20% and 27%. A single tracking system leads to an increase of 20-25% in system output compared to a system without tracking.

Key economic assumptions include: O&M expenses, RECs with a $.015/kWh value, and minimal Federal incentives.

2 **Economic Assumptions**

Factor[1]	Assumption	Comments
System Life	30 years	• Typical for crystalline silicon technologies.
O&M Cost ($/kW/year)	$ 27/ kW/ year	• Central systems incur O&M expenses to ensure PV panels are clean and maintenance of the tracking system which has moving parts.
Replacement Expenditure	Yes	• Inverters will be replaced once during Year 10 of the project life. Cost of inverter is assumed at around $210/W based on current prices and trends.
State Incentives	No	• No state incentives are assumed.
Federal Tax Credits (%)	10	• Federal Investment Tax Credit of 10% has been available for several years and does not have an expiration. Assumed that this will be applicable to central PV.
Accelerated Depreciation	MACRS 5 year class	• Federal incentive that currently exists and is likely to continue. Applicable to commercial customers.
REC[2] Value ($/kWh)	0.015	• Assumption reflects the federal cap of $15/MWh. Current PV REC values are much higher, reflecting limited availability in trading system.
Net Metering	Not relevant	• Not relevant for central PV systems.
Discount Rate	6.35%	• Assumes debt equity ratio of 3:1, cost of debt at 7.5%, cost of equity at 12%, marginal federal income tax at 34% and state income tax at 6.5%.

1) All data are in 2010 dollars 2) REC = Renewable Energy Certificate

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The competing technology considered is a gas turbine peak generation plant.

3

Cost of Fossil Fuel Alternative

Fossil Fuel Alternative: Gas Turbine[1]	
Capital Cost	$71.92/kW/year (Fully loaded cost)
O&M Expenses (non-fuel)	$2.00 / MWh
Fuel Cost	$/MMBTU: $5 and $3 Heat rate: 10,500 BTU/kWh
Capacity Factor	8%, 10% and 15% (range for a peak plant)

Key Comments

- A PV central plant will compete most effectively with a peaking plant, given the characteristics of PV system output, which matches peak demand. Cost and performance of a GT generator peak plant is assumed for comparison.
- A range of values has been considered for two key assumptions, i.e. fuel cost and capacity factor

1) NCI Estimates

While utilities do not typically use the payback metric in their decision, this was used to provide an estimate of demand[1].

4

Payback Period

Payback Period						
Fuel Cost	**$5.0 / MMBTU**			**$3.0 / MMBTU**		
GT Capacity Factor	**8%**	**10%**	**15%**	**8%**	**10%**	**15%**
PV System Cost	**Payback Period (Years)**					
$1.00/Wpdc	3	4	5	4	5	6
$2.00/Wpdc	8	11	16	11	14	25
$3.00/Wpdc	19	28	>50	28	50	N/A
$4.00/Wpdc	>50	>50	N/A	>50	N/A	N/A

Key Comments

- Utilities use investment metrics such as IRR and NPV to make investment decisions. However, there is limited data available to estimate market potential based on these metrics. Hence, the payback metric was used to provide an estimate of demand.
- The payback period is calculated by taking into account the initial capital investment required for the PV system, the differential in the levelized cost of energy (LCOE) between the PV system and the fossil fuel alternative, value of RECs, and the output of the PV system. In addition, values associated with PV system for emission allowance and fuel price risk mitigation are estimated at around $50/kW/year.[2]
- In the case where the LCOE of PV plant and consideration of REC results in a cost higher than that of the fossil fuel alternative, payback is not calculated.

1) A curve that relates financial return (IRR) or comparative cost difference between two energy sources (in %) and market penetration by a technology is not available within NCI or in the public domain. Hence the payback curve was used to provide an estimate of demand in the utilities sector.
2) NCI estimates based on NOx + CO_2 at $10/ton and 800lb/MWh; and Austin Energy's green fixed price premium

The market potential model used for the utility segment is similar to that for the residential/commercial segments, with some differences.

5

Market Potential Model

Key Comments	
Technical Market Potential - 2025	• The technical market potential is the total demand for peak power in 2025. • In California, peak demand during 2025 is estimated at 67,529 MW
Cumulative Market Penetration - 2025	The cumulative market penetration by PV of the peak power market in 2025 is calculated using the average of the Kastovich and NCI curves (payback versus market penetration) as discussed in the section on residential and commercial demand.
S-Curve	The S curve used for the utility segment is similar to that for the residential segment, with a small difference in that for the residential and commercial segment, PV had penetrated the market by 2003, albeit to a very small percentage, while for the utility segment, the market penetration is for practical purposes, nil.

The potential demand for central PV in California in 2010 is estimated at 9-500 MWp, depending natural gas price and GT capacity factor.

6

Potential Demand in 2010

Central PV Potential Demand in 2010						
Fuel Cost	**$5.0 / MMBTU**			**$3.0 / MMBTU**		
GT Capacity Factor	**8%**	**10%**	**15%**	**8%**	**10%**	**15%**
PV System Cost	**Annual Demand in 2010 (MW)**					
$1.00/Wpdc	500	452	312	452	367	201
$2.00/Wpdc	90	20	9	20	12	0
$3.00/Wpdc	5	0	0	0	0	0
$4.00/Wpdc	0	0	0	0	0	0

Demand for central PV is nil when the payback is more than 20 years.

Table of Contents

1 » Introduction

2 » Executive Summary

3 » Market Potential for Grid Connected PV

4 » **Market Barriers**

5 » Attractive States for PV

6 » Appendix

To realize the market potential for PV, technological, institutional and market infrastructure barriers need to be addressed.

Market Barriers for PV

Technological

- High manufacturing and total installed system cost

Institutional

- Lack of consistent and long-term funds for buy-down programs
- Lack of interconnection standards
- Wide-spread net metering policies for all sizes of PV
- Uncertainty about the value of Renewable Energy Certificates in the marketplace

Market Infrastructure

- Installer training
- Building inspector and code official training
- Consumer education about the technology

The industry must address the barriers taking into account their impact and the resources and time required to redress them.

Barriers	Impact of Barrier		Ease of Redress	
	Rating	Comments	Rating	Comments
High manufacturing and total installed system cost	●	• High first cost is the most significant barrier to PV adoption	○	• Manufacturing improvements have been incremental over the past decade
Lack of interconnection standards	◒	• Interconnection costs or penalties can result in uneconomic installations of PV	◒	• Many states are moving to establish quicker and cheaper processes for PV interconnection
Wide-spread net metering policies for all sizes of PV	●	• Lack of net metering policies can ruin the economics of a PV system	◒	• Over 35 states in the U.S. currently have net metering policies for small PV systems
Uncertainty about RECs values	○	• Many owners of PV systems currently do not receive value from the sale of RECs	●	• MA has implemented a program already to guarantee payment on RECs for 10 years
Lack of long-term funds for buy-down programs	◒	• Without buy-downs, the grid-connected PV market would probably not exist in the U.S.	●	• Creative business models or phasing out of buy-downs can help to overcome this barrier
Installer training	○	• Poor installations result in reduced output, but does not prevent the system from working	●	• Many state programs are focusing on installer training activities
Building inspector and code official training	◒	• Lack of knowledge about PV can hinder inspection approvals	●	• As volumes and knowledge of PV increases, this issue should resolve itself
Consumer education	◒	• Many consumers still associate PV with the poor performance of solar hot water systems in the 1980s	●	• Educational campaigns can help overcome this barrier

○ = Low ◒ = Medium ● = High

Potential solutions to the key barriers include:

Barriers	Potential Solutions
High manufacturing and total installed system cost	Provide funding support to manufacturers to expand R&D and manufacturing capacities or establish stable customer incentive "buy-down" funding to encourage investment in manufacturing plant.
Lack of interconnection standards	Work with state agencies to develop interconnection standards.
Wide-spread net metering policies for all sizes of PV	Work with state agencies to develop net metering policies that are for residential and commercial size PV systems.
Uncertainty about RECs values	Try to replicate MA model of REC value guarantees in other states and with other state renewable energy funds.
Lack of long-term funds for buy-down programs	Develop other creative business models so there is not complete reliance on state buy-down programs. If buy-downs are implemented, ensure that they are phased out over time to create a sustainable market. Review Japanese buy-down program.
Installer training	Several states have implemented very good installer training programs that can be replicated in other states.
Building inspector and code official training	Use Clean Energy States Alliance (CESA) or individual state funds to help educate and train building inspectors and code officials about PV.
Consumer education	Provide more TV adds or educational campaigns to educate consumers about the high reliability of PV and the benefits to the environment.

Table of Contents

1 » Introduction

2 » Executive Summary

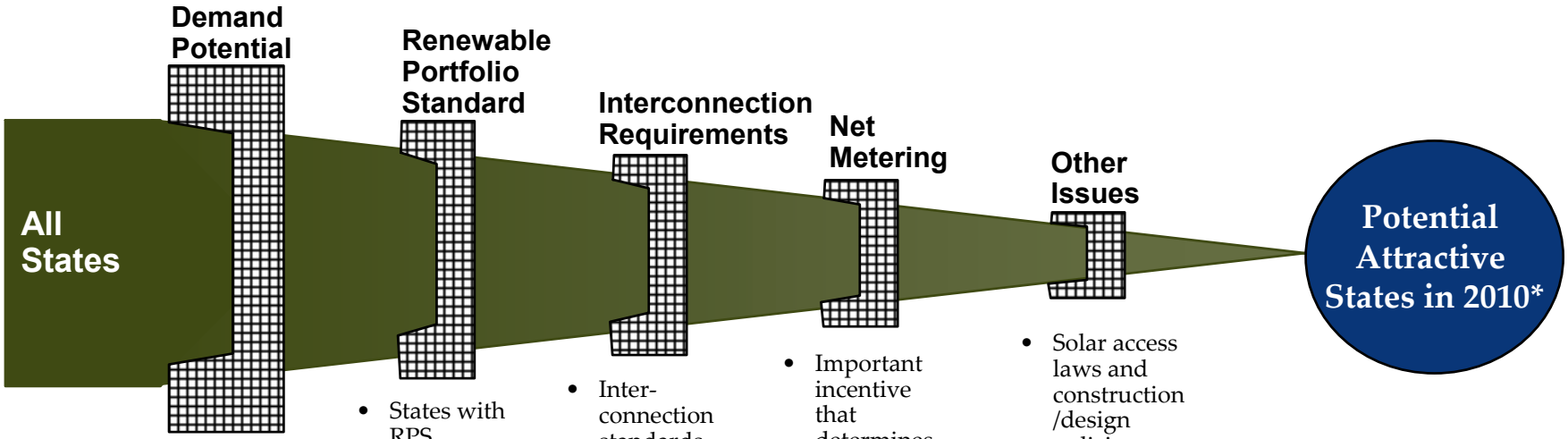
3 » Market Potential for Grid Connected PV

4 » Market Barriers

5 » Attractive States for PV

6 » Appendix

Potentially attractive states for grid connected PV systems were identified by taking into account five criteria.



- Assessment based on utility rates, solar resources and roof space availability
- Large markets are attractive!
- Focus on demand from the roof-top residential and commercial market segments.

- States with RPS encourages consideration of PV, and provides impetus for development of REC market

- Inter-connection standards and streamline processes for PV systems

- Important incentive that determines PV economics

- Solar access laws and construction /design policies can impact customer choice

*This is not indicative of the best current state markets for PV in the U.S., that are largely driven by state buy-down programs and rebates.

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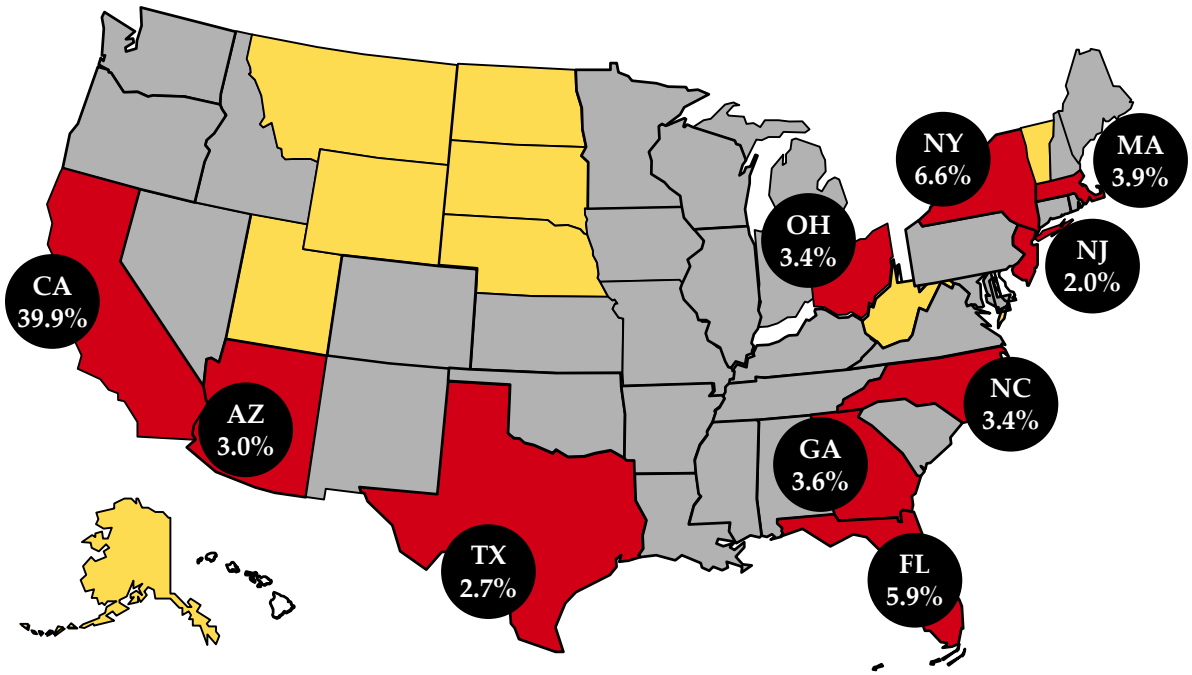
The top ten states together account for 74% of the total potential demand of 2,901 MWp in 2010 at a system price of $2.00-2.50/Wpdc.

Potential Grid Connected Demand in 2010 By State: % Share of Total



Ranking

1. CA
2. NY
3. FL
4. MA
5. GA
6. NC
7. OH
8. AZ
9. TX
10. NJ

U.S Total 2,901 MWp

= Top Ten States = Bottom Ten States = 'In-between' States

Note: Based on analysis conducted for this study. See earlier part of report. Potential demand in 2010 by segment (residential, commercial, total) by state and different system price scenarios is provided in the Appendix. This is not indicative of the best current state markets for PV in the U.S., that are largely driven by state buy-down programs and rebates.

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Amongst the top ten states identified by demand potential, seven have or are considering RPS.

#	State	RPS Status			Rating		
		% Required	By Year	Other Issues/ Comments	High	Medium	Low
1	California	20%	2017	Minimum 1% increase every year	√		
2	New York			Currently implementing an RPS with Solar set-aside		√	
3	Florida	No state RPS standard					√
4	Massachusetts	4%	2009		√		
5	Georgia	No RPS standard					√
6	Ohio	No RPS standard					√
7	North Carolina			Considering RPS		√	
8	Arizona	1.1%*	2007	Solar should be 60%	√		
9	Texas	2.2% or 2,000 MW	2009		√		
10	New Jersey	6.5%	2012	Minimum of 4% from Class-I sources, which includes solar	√		

* RPS requirement is 0.8% in 2004. If PV does not reach a cost – benefit status agreeable to by the Commission by 2004, RPS standard will not increase beyond 2004.

Five states have interconnection standards that make it easy for customers to install PV systems of a reasonable size.

#	State	Interconnection Status			Rating		
		State Standards	Maximum System Size Eligibility	Other Issues	High	Medium	Low
1	California	√	≤ 10 MW		√		
2	New York	√	≤ 300 kVA	Developing standby changes (except for residential systems of ≤ 10 kW)	√		
3	Florida	√ (for IOUs, not munis or coops)	≤ 10 kW	Requires $100K liability insurance by customer		√	
4	Massachusetts	√	≤ 60 kW			√	
5	Georgia	√	≤ 10 kW Residential ≤ 100 kW Commercial			√	
6	Ohio	√	≤ 300 kVa		√		
7	North Carolina						√
8	Arizona	√ (by major utilities)			√		
9	Texas	√	≤ 10 MW at 60 kV or less		√		
10	New Jersey	√			√		

Nine states offer net metering, though some states restrict the PV system size eligible for net metering.

#	State	Net Metering Status				Rating		
		Applicable	System Size Eligibility	Cumulative PV Installation Eligibility	Other Issues	High	Medium	Low
1	California	√ (state wide)		Up to 0.5% utility peak demand	No exit fees	√		
2	New York	√ (state wide)	<10kW	Up to 0.1% utility peak demand		√		
3	Florida	√ (by each utility)				√		
4	Massachusetts	√	≤ 60 kW				√	
5	Georgia	√	≤ 10 kW Residential ≤ 100 kW Commercial	Up to 0.2% of utility peak demand			√	
6	Ohio	√				√		
7	North Carolina							√
8	Arizona	√	≤ 10 kW (APS) ≤ 500 kW (TEP)			√		
9	Texas	√	≤ 50 kW				√	
10	New Jersey	√	≤ 100 kW	Up to 0.1% utility peak demand			√	

Six states allow solar easements which ensures optimal PV system operation during the system life.

#	State	Other Issues		Rating		
		Solar Access Laws/ Guidelines	Construction & Design Issues	High	Medium	Low
1	California	• Solar easements allowed* • Restrictive covenants prohibited** • Cities have specific requirements, e.g, encouraging buildings oriented for PV, relaxing building height restrictions if PV installed, etc.	Solar to be installed on all state buildings where feasible by January 1, 2007, as well as on new state buildings and park constructions	√		
2	New York	• Solar easements allowed • Local zoning districts can make own rules		√		
3	Florida	• Prohibits covenants restricting access/use of solar energy			√	
4	Massachusetts	• Solar easements allowed • Prohibits restrictive covenants		√		
5	Georgia	• Solar easements allowed • Prohibits restrictive covenants		√		

* Easements provide assured access to solar resource after PV system is installed.
** Covenants that restrict installation of PV system by building owner, associations, etc.

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Six states allow solar easements which ensures optimal PV system operation during the system life. *(Continued)*

#	State	Other Issues		Rating		
		Solar Access Laws/ Guidelines	Consideration & Design Issues	High	Medium	Low
6	Ohio	• Solar easements allowed		√		
7	North Carolina					√
8	Arizona	• Restrictive covenants prohibited	New state buildings should follow solar design and install PV if payback ≤ 8 years		√	
9	Texas		State government to evaluate PV			√
10	New Jersey	• Solar easements allowed		√		

Seven states are the most attractive for PV, namely California, New York, Massachusetts, Ohio, Arizona, Texas and New Jersey.

#	State	Attractiveness Based on Criteria					Overall Attractiveness*
		Demand Potential	RPS	Interconnection Requirement	Net Metering	Other Issues	
1	California	●	●	●	●	●	●
2	New York	●	◒	●	●	●	●
3	Florida	●	○	◒	●	◒	◒
4	Massachusetts	●	●	◒	◒	●	●
5	Georgia	●	○	◒	◒	●	◒
6	Ohio	●	○	●	●	●	●
7	North Carolina	●	◒	○	○	○	○
8	Arizona	●	●	●	●	◒	●
9	Texas	●	●	●	◒	○	●
10	New Jersey	●	●	●	◒	●	●

○ = Unfavorable ◒ = Medium ● = Favorable

* High if rated Favorable on at least three criteria, Medium if rated Favorable on at least two criteria, Low if rated Favorable on one or no criteria.

Table of Contents

1 » Introduction

2 » Executive Summary

3 » Market Potential for Grid Connected PV

4 » Market Barriers

5 » Attractive States for PV

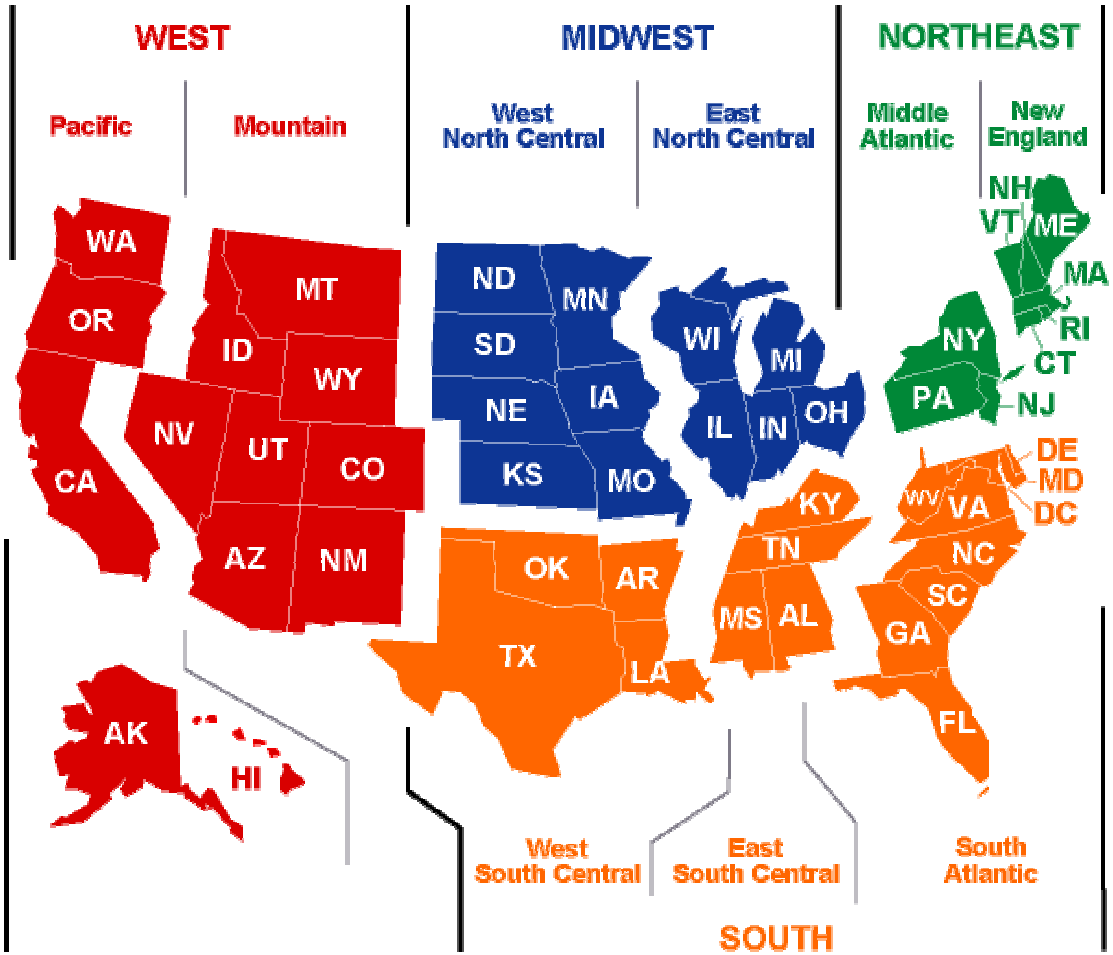
6 » Appendix

List of Appendices

6 » Appendix

- **A1 »** Census Regions
- **A2 »** Locations and Utilities Selected for Analysis
- **A3 »** Average Customer Load
- **A4 »** Number of Customers
- **A5 »** Clean-Power Estimator™ Model
- **A6 »** Payback
- **A7 »** Available Roof Area
- **A8 »** Technical Market for PV
- **A9 »** Annual Demand in 2010
- **A10 »** Annual Demand in 2015
- **A11 »** Annual Demand in 2010 with Alternative Curves

There are nine Census regions.



NAVIGANT CONSULTING

The locations and utilities selected determine the insolation and utility rates used to represent the entire state in our analysis.

State	Location	Utility
Midwest - East North Central		
Illinois	Chicago	Commonwealth Edison Co.
Indiana	Indianapolis	Indianapolis Power and Light
Michigan	Detroit	Detroit Edison
Ohio	Cleveland	FirstEnergy Corp (The Illuminating Company)
Wisconsin	Milwaukee	We Energies (Wisconsin Electric)
Midwest - West North Central		
Iowa	Cedar Rapids	IES Utilities
Kansas	Topeka	Kansas Power and Light (Western Resources)
Minnesota	St. Paul	Xcel Energy (Northern States Power)
Missouri	Jefferson City	AmerenUE - Missouri (Union Electric)
Nebraska	Lincoln	Lincoln Electric
North Dakota	Bismarck	Montana-Dakota Utilities
South Dakota	Sioux Falls	Xcel Energy (Northern States Power)
NorthEast - Middle Atlantic		
New Jersey	Trenton	PSE&G (Public Service Electric and Gas Co.)
New York -1	Albany	Niagara Mohawk
New York -2	New York	Consolidated Edison
New York -3	New York	Long Island Power Authority
Pennsylvania	Harrisburg	PPL Electric Utilities
NorthEast - New England		
Connecticut	Hartford	Connecticut Light and Power
Maine	Augusta	Central Maine Power
Massachusetts	Boston	NSTAR (Boston Edison)
New Hampshire	Manchester	Public Service of New Hampshire
Rhode Island	Providence	Narragansett Electric
Vermont	Montpelier	Green Mountain Power
South - East South Central		
Alabama	Montgomery	Alabama Power Co.
Kentucky	Frankfort	American Electric Power (Kentucky Power)
Mississippi	Jackson	Entergy Mississippi (Mississippi Power and Light)
Tennessee	Nashville-Davidson	Nashville Electric Service

State	Location	Utility
South - South Atlantic		
Delaware	Newark	Conective (Delmarva Power)
Florida	Miami	Florida Power & Light Co.
Georgia	Atlanta	Georgia Power
Maryland	Annapolis	BGE (Baltimore Gas and Electric)
North Carolina	Charlotte	Duke Power
South Carolina	Columbia	South Carolina Electric and Gas
Virginia	Richmond	Dominion (Virginia Electric and Power)
Washington, DC	Washington	PEPCO
West Virginia	Charleston	American Electric (Appalachian Power)
South - West South Central		
Arkansas	Little Rock	Entergy Arkansas
Louisiana	New Orleans	Entergy (Louisiana Power & Light)
Oklahoma	Tulsa	AEP (Public Service Company of Oklahoma)
Texas	Dallas	TXU Electric
West - Mountain		
Arizona	Phoenix	APS
Colorado	Denver	Public Service Company of Colorado
Idaho	Boise City	Idaho Power
Montana	Helena	Northwestern Energy (Montana Power Company)
Nevada	Las Vegas	Nevada Power
New Mexico	Santa Fe	PNM (Public Service Company of New Mexico)
Utah	Salt Lake City	PacifiCorp (Utah Power & Light)
Wyoming	Casper	PacifiCorp (Pacific Power)
West - Pacific		
Alaska	Anchorage	Chugach
California -1	Long Beach	Southern California Edison (SCE)
California -2	Sacramento	Sacramento Municipal Utility District (SMUD)
California -3	San Jose	Pacific Gas and Electric Company (PG&E)
Hawaii	Honolulu	Hawaiian Electric Company (Oahu)
Oregon	Portland	PacifiCorp (Pacific Power)
Washington	Olympia	Puget Sound Energy

Note:
- State capitals typically have the highest population, and largest building stock for both commercial and residential buildings in the state.
- Solar resource data is available for all state capitals.
- In the case of California and New York, because of the combination of good solar resource and different tiered or wide range of electricity tariff structures, we took into account two additional cities.

NAVIGANT CONSULTING

Average customer load in kWh/year, by state and segment[1].

Average consumption (kWh/year)			
State	Residential	Commercial: Small/Med	Commercial: Large
Midwest - East North Central			
Illinois	8,711	87,455	7,394,237
Indiana	11,427	86,112	2,344,113
Michigan	7,788	74,755	2,480,151
Ohio	9,826	70,344	70,344
Wisconsin	8,634	65,732	4,673,847
Regional Weighted Average	**9,157**	**76,979**	**3,282,208**
Midwest - West North Central			
Iowa	9,945	49,110	4,050,919
Kansas	10,543	67,023	729,050
Minnesota	9,333	85,583	3,963,724
Missouri	12,246	80,681	1,685,644
Nebraska	11,797	59,104	729,961
North Dakota	11,939	64,680	64,680
South Dakota	10,928	56,212	1,048,383
Regional Weighted Average	**10,830**	**70,492**	**2,148,511**
NorthEast - Middle Atlantic			
New Jersey	7,934	81,329	938,889
New York -1	6,532	65,638	2,472,830
New York -2	6,532	65,638	2,472,830
New York -3	6,532	65,638	2,472,830
Pennsylvania	9,081	54,710	1,384,796
Regional Weighted Average	**7,694**	**64,599**	**1,760,078**
NorthEast - New England			
Connecticut	8,573	92,465	947,327
Maine	7,208	60,283	2,777,927
Massachusetts	7,126	76,125	809,128
New Hampshire	6,934	45,206	754,247
Rhode Island	6,464	77,338	547,171
Vermont	7,028	46,124	46,124
Regional Weighted Average	**7,412**	**72,109**	**970,213**
South - East South Central			
Alabama	14,281	59,196	5,258,472
Kentucky	13,229	59,565	6,186,238
Mississippi	14,222	60,206	3,449,249
Tennessee	15,177	67,016	16,902,980
Regional Weighted Average	**14,312**	**62,111**	**9,128,569**

Average consumption (kWh/year)			
State	Residential	Commercial: Small/Med	Commercial: Large
South - South Atlantic			
Delaware	10,895	90,209	5,872,970
Florida	13,806	81,344	817,951
Georgia	12,716	88,536	3,425,552
Maryland	11,910	115,183	834,362
North Carolina	12,649	71,434	71,434
South Carolina	13,883	68,368	5,889,721
Virginia	13,227	92,524	3,630,781
Washington, DC	8,605	267,426	279,693,635
West Virginia	11,917	56,477	969,271
Regional Weighted Average	**13,053**	**84,136**	**4,596,780**
South - West South Central			
Arkansas	12,702	61,779	663,524
Louisiana	14,140	79,578	1,876,633
Oklahoma	12,984	65,414	65,414
Texas	14,059	77,049	77,049
Regional Weighted Average	**13,818**	**74,664**	**358,665**
West - Mountain			
Arizona	12,891	101,067	1,851,363
Colorado	7,930	72,581	1,383,645
Idaho	12,712	68,638	1,134,733
Montana	9,454	46,956	46,956
Nevada	11,602	57,780	5,887,283
New Mexico	6,824	62,123	3,688,728
Utah	8,671	94,240	857,299
Wyoming	9,557	58,139	58,139
Regional Weighted Average	**10,166**	**74,737**	**2,020,298**
West - Pacific			
Alaska	8,060	59,096	1,188,636
California - 1	6,528	64,240	520,152
California - 2	6,528	64,246	520,167
California - 3	6,528	64,246	520,157
Hawaii	7,473	57,092	5,794,191
Oregon	12,035	70,322	1,061,215
Washington	12,808	83,901	1,062,193
Regional Weighted Average	**8,008**	**67,167**	**791,503**
National Weighted Average	**10,520**	**72,893**	**2,783,283**

1) Source: EIA, US Average Monthly Bill by Sector, Census Division and State, 2001. Assumption made that load per customer remains constant with time.
2) Note 1: The EIA commercial segment data is assumed for small/medium commercial while EIA industrial segment data is assumed for large commercial.
3) Note 2: Weighting is done by number of customers by segment, by state (EIA data, 2001), which is provided in the appendix.

For the purpose of analysis, NCI used the 2001[1] EIA data on number of customers by segment in each state.

Number of Customers (2001)					
State	Residential Total	Commercial Total	Total	% share of U.S Total	% share of Residential
Midwest - East North Central					
Illinois	4,801,256	501,175	5,302,431	4%	90.5%
Indiana	2,574,672	296,676	2,871,348	2%	89.7%
Michigan	4,147,897	466,654	4,614,551	4%	89.9%
Ohio	4,817,008	561,554	5,378,562	4%	89.6%
Wisconsin	2,364,921	284,113	2,649,034	2%	89.3%
Regional subtotal	**18,705,754**	**2,110,172**	**20,815,926**	**16%**	**89.9%**
Midwest - West North Central					
Iowa	1,249,933	173,308	1,423,241	1%	87.8%
Kansas	1,144,180	190,752	1,334,932	1%	85.7%
Minnesota	2,078,775	231,313	2,310,088	2%	90.0%
Missouri	2,463,550	322,570	2,786,120	2%	88.4%
Nebraska	732,255	122,346	854,601	1%	85.7%
North Dakota	291,483	47,468	338,951	0%	86.0%
South Dakota	327,661	51,852	379,513	0%	86.3%
Regional subtotal	**8,287,837**	**1,139,609**	**9,427,446**	**7%**	**87.9%**
NorthEast - Middle Atlantic					
New Jersey	3,204,881	418,567	3,623,448	3%	88.4%
New York -1	1,820,572	244,402	2,064,974	2%	88.2%
New York -2	3,641,144	488,804	4,129,948	3%	88.2%
New York -3	1,281,143	171,986	1,453,130	1%	88.2%
Pennsylvania	5,097,755	803,274	5,901,029	5%	86.4%
Regional subtotal	**15,045,495**	**2,127,033**	**17,172,528**	**13%**	**87.6%**
NorthEast - New England					
Connecticut	1,395,720	134,542	1,530,262	1%	91.2%
Maine	657,079	74,250	731,329	1%	89.8%
Massachusetts	2,520,474	328,099	2,848,573	2%	88.5%
New Hampshire	546,402	86,516	632,918	0%	86.3%
Rhode Island	417,355	48,207	465,562	0%	89.6%
Vermont	285,905	42,435	328,340	0%	87.1%
Regional subtotal	**5,822,935**	**714,049**	**6,536,984**	**5%**	**89.1%**
South - East South Central					
Alabama	1,946,833	318,692	2,265,525	2%	85.9%
Kentucky	1,791,468	240,678	2,032,146	2%	88.2%
Mississippi	1,185,264	188,617	1,373,881	1%	86.3%
Tennessee	2,433,410	387,520	2,820,930	2%	86.3%
Regional subtotal	**7,356,975**	**1,135,507**	**8,492,482**	**7%**	**86.6%**

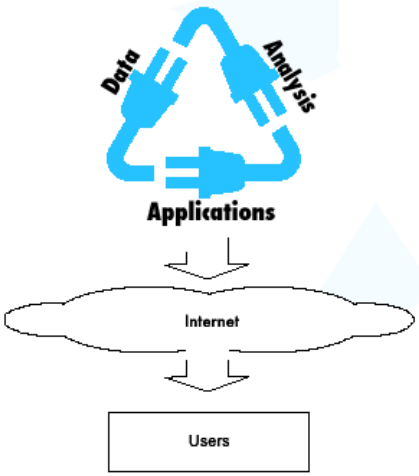
Number of Customers (2001)					
State	Residential Total	Commercial Total	Total	% share of U.S Total	% share of Residential
South - South Atlantic					
Delaware	342,747	40,267	383,014	0%	89.5%
Florida	7,343,128	908,971	8,252,099	6%	89.0%
Georgia	3,490,148	427,323	3,917,471	3%	89.1%
Maryland	2,016,667	220,320	2,236,987	2%	90.2%
North Carolina	3,652,769	528,310	4,181,079	3%	87.4%
South Carolina	1,791,811	255,700	2,047,511	2%	87.5%
Virginia	2,816,818	313,888	3,130,706	2%	90.0%
Washington, DC	194,925	27,307	222,232	0%	87.7%
West Virginia	824,784	120,134	944,918	1%	87.3%
Regional subtotal	**22,473,797**	**2,842,220**	**25,316,017**	**20%**	**88.8%**
South - West South Central					
Arkansas	1,189,161	148,144	1,337,305	1%	88.9%
Louisiana	1,824,750	222,671	2,047,421	2%	89.1%
Oklahoma	1,524,652	207,143	1,731,795	1%	88.0%
Texas	8,344,840	1,144,915	9,489,755	7%	87.9%
Regional subtotal	**12,883,403**	**1,722,873**	**14,606,276**	**11%**	**88.2%**
West - Mountain					
Arizona	2,032,358	218,170	2,250,528	2%	90.3%
Colorado	1,824,528	246,447	2,070,975	2%	88.1%
Idaho	543,244	95,318	638,562	0%	85.1%
Montana	410,997	77,615	488,612	0%	84.1%
Nevada	828,100	115,820	943,920	1%	87.7%
New Mexico	732,626	110,147	842,773	1%	86.9%
Utah	771,928	87,659	859,587	1%	89.8%
Wyoming	224,499	50,134	274,633	0%	81.7%
Regional subtotal	**7,368,280**	**1,001,310**	**8,369,590**	**6%**	**88.0%**
West - Pacific					
Alaska	234,646	38,282	272,928	0%	86.0%
California -1	3,947,048	519,753	4,466,801	3%	88.4%
California -2	3,947,048	519,753	4,466,801	3%	88.4%
California -3	3,947,048	519,753	4,466,801	3%	88.4%
Hawaii	375,015	54,804	429,819	0%	87.2%
Oregon	1,454,426	210,665	1,665,091	1%	87.3%
Washington	2,468,000	284,113	2,752,113	2%	89.7%
Regional subtotal	**16,373,231**	**2,147,122**	**18,520,353**	**14%**	**88.4%**
Total	**114,317,707**	**14,939,895**	**129,257,602**	**100%**	**88.4%**

Notes:

- Source: EIA, US Average Monthly Bill by Sector, Census Division and State, 2001. Building data is available by Census regions and not be states. The number of customers data is used as weights in calculating the roof area by state. The implicit assumption in our analysis is that the percent share of customers within the states in a region will not change with time.
- Commercial Total = Total of Commercial Small/Medium and Commercial Large
- Total number of customers for New York and California are distributed across the three locations based on the percentage share of customers of the three relevant utilities.

Overview

The Estimator is a suite of Internet-based applications designed to help consumers evaluate the cost-effectiveness of clean energy systems. It provides a personalized estimate of the costs and benefits of a system for a specific residential or commercial customer. The Estimator's three critical components are data, analysis, and applications. The applications can be used to support the objectives of equipment manufacturers, resellers and dealers, utilities and state agencies, and the federal government.



Users

Equipment Manufacturers

- Expand Web Presence
- Generate Quality Sales Leads
- Assess New Markets
- Offer Targeted Incentives

Resellers and Dealers

- Screen Potential Customers
- Produce Professional Sales Quotations
- Meet with Customers
- Assess Site Feasibility

State Agencies and Utilities

- Educate Consumers
- Support Incentive Programs
- Assist in Rebate Processing
- Evaluate System Performance

Federal Government

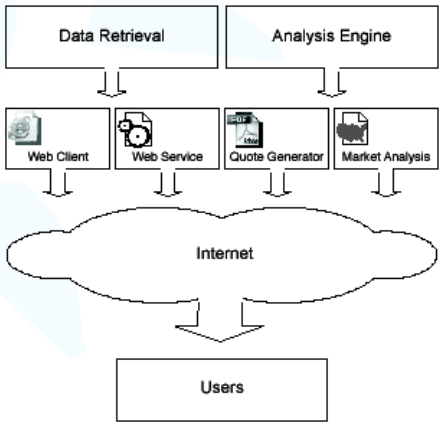
- Promote Clean Energy Technologies
- Evaluate Potential New Incentives
- Answer Complex Research Questions

Applications

Estimator applications inclue the Web Client, Web Service, Quote Generator, and Market Analysis programs. All of these programs make use of the Estimator databases and analysis engine.

The databases include information about electric rate tariffs, incentive programs, solar resource, load profiles, emissions factors and tax information.

The analysis engine contains the algorithms, based on many years of research, necessary to calculate cost-effectiveness.



NAVIGANT CONSULTING

Payback in 2010 by state, segment and at different system prices is shown below.

STATE	PAYBACK (years) IN 2010											
	Residential				Commercial Small/Med				Commercial Large			
System price in 2010 ($/Wpdc) >>	$1.25	$2.50	$3.75	$5.30	$1.10	$2.20	$3.30	$4.65	$1.00	$2.00	$3.00	$4.25
Midwest - East North Central												
Illinois	7	13	17	21	7	10	12	14	5	8	10	12
Indiana	11	18	22	26	8	12	14	15	7	11	13	15
Michigan	7	12	16	20	6	10	12	14	6	9	11	13
Ohio	6	10	14	17	5	8	10	12	6	9	11	13
Wisconsin	7	12	16	20	6	9	11	13	6	9	11	12
Regional Weighted Average	**7**	**13**	**16**	**20**	**6**	**10**	**12**	**13**	**6**	**9**	**11**	**13**
Midwest - West North Central												
Iowa	7	12	15	19	6	9	11	12	6	9	10	12
Kansas	8	14	18	22	9	13	14	16	9	13	15	16
Minnesota	8	13	17	21	7	10	12	13	7	10	11	13
Missouri	8	14	18	22	8	11	13	14	6	9	11	13
Nebraska	9	14	19	22	8	11	13	14	8	11	13	14
North Dakota	8	14	17	21	7	10	12	13	9	12	13	14
South Dakota	8	14	18	22	8	12	14	16	8	12	14	16
Regional Weighted Average	**8**	**13**	**18**	**21**	**8**	**11**	**13**	**14**	**7**	**10**	**12**	**14**
NorthEast - Middle Atlantic												
New Jersey	5	10	13	16	5	8	10	12	5	8	10	11
New York - 1	7	12	15	19	5	8	10	11	4	7	9	10
New York - 2	4	8	11	14	5	8	10	11	4	6	8	10
New York - 3	5	9	12	16	4	7	9	11	3	6	8	9
Pennsylvania	8	13	18	22	6	9	11	12	6	9	11	13
Regional Weighted Average	**6**	**11**	**14**	**18**	**6**	**8**	**10**	**12**	**5**	**8**	**10**	**11**
NorthEast - New England												
Connecticut	7	11	15	19	6	9	11	12	6	9	11	13
Maine	5	9	13	16	5	8	10	11	4	7	9	11
Massachusetts	5	9	12	15	4	7	8	10	5	7	9	11
New Hampshire	6	10	14	18	6	9	11	13	5	8	10	12
Rhode Island	6	10	13	17	5	8	10	11	6	9	11	12
Vermont	6	10	14	17	6	9	11	12	9	12	14	15
Regional Weighted Average	**5**	**10**	**13**	**17**	**5**	**8**	**10**	**11**	**5**	**8**	**10**	**12**
South - East South Central												
Alabama	8	13	17	21	6	9	11	13	7	10	12	14
Kentucky	9	15	19	23	8	12	13	14	7	10	12	13
Mississippi	9	14	19	23	7	11	13	14	8	11	13	15
Tennessee	8	14	18	22	6	10	12	13	6	9	11	12
Regional Weighted Average	**8**	**14**	**18**	**22**	**7**	**10**	**12**	**14**	**6**	**10**	**12**	**13**

Source: Analysis by Clean-Power Research and NCI

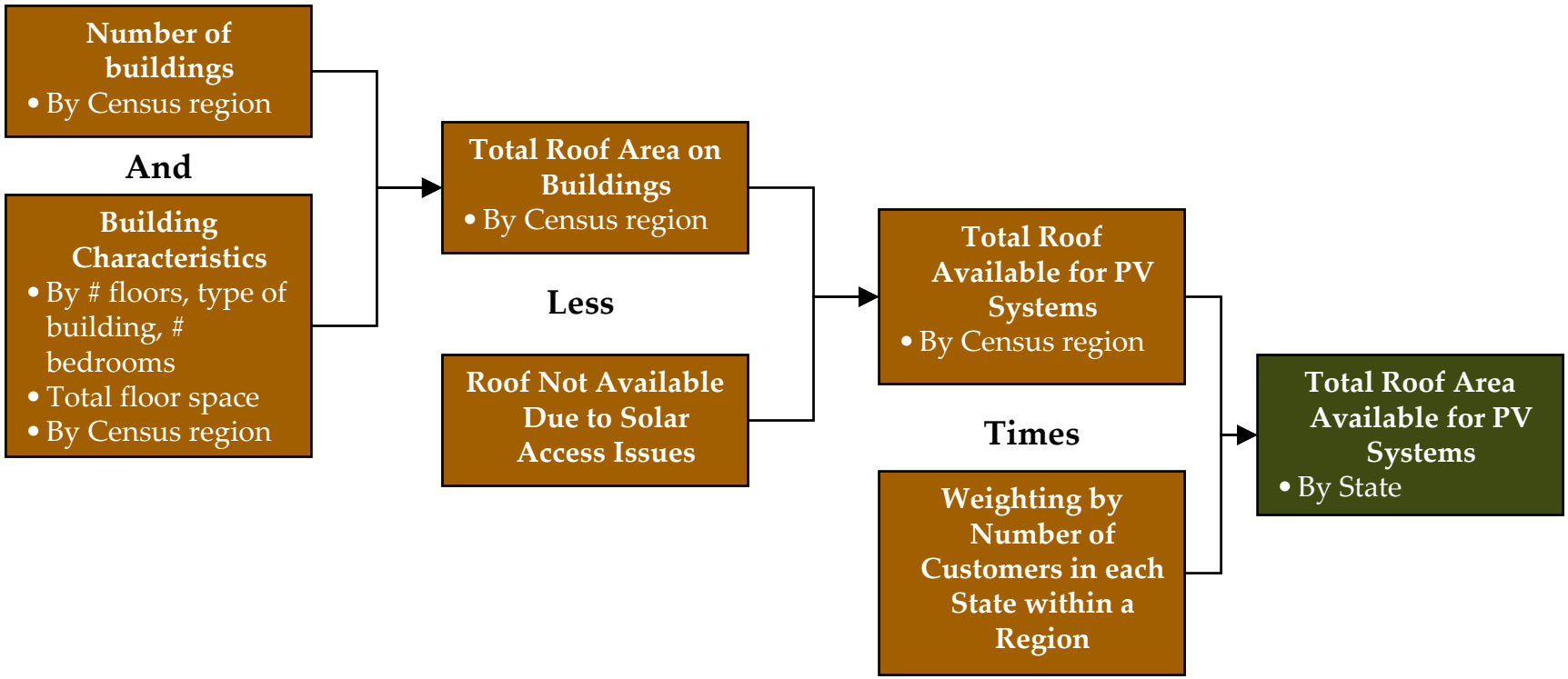
Payback in 2010 by state, segment and at different system prices is shown below (continued).

STATE	PAYBACK (years) IN 2010											
	Residential				Commercial Small/Med				Commercial Large			
System price in 2010 ($/Wpdc) >>	$1.25	$2.50	$3.75	$5.30	$1.10	$2.20	$3.30	$4.65	$1.00	$2.00	$3.00	$4.25
South - South Atlantic												
Delaware	7	12	16	19	5	8	10	12	6	9	11	12
Florida	6	11	15	19	6	9	11	12	6	9	11	13
Georgia	7	12	16	20	5	8	10	12	5	8	10	12
Maryland	7	13	17	21	6	10	12	13	7	10	12	13
North Carolina	7	12	16	19	5	8	10	12	7	10	12	14
South Carolina	7	11	15	19	6	9	11	13	8	12	14	15
Virginia	7	13	17	20	7	11	12	14	9	13	14	16
Washington, DC	6	11	15	18	6	9	10	12	5	8	10	11
West Virginia	11	17	22	25	8	11	13	14	9	12	13	14
Regional Weighted Average	**7**	**12**	**16**	**20**	**6**	**9**	**11**	**12**	**7**	**10**	**12**	**13**
South - West South Central												
Arkansas	8	13	17	21	7	10	12	14	9	12	14	15
Louisiana	6	11	14	18	6	9	10	12	6	9	11	12
Oklahoma	8	14	18	22	8	11	13	15	10	13	15	16
Texas	7	12	16	20	7	10	12	14	8	11	13	15
Regional Weighted Average	**7**	**12**	**16**	**20**	**7**	**10**	**12**	**14**	**8**	**11**	**13**	**15**
West - Mountain												
Arizona	5	9	12	15	5	8	10	12	5	8	10	12
Colorado	8	13	17	21	7	10	12	14	7	10	12	14
Idaho	8	14	18	21	7	10	11	13	8	12	13	14
Montana	7	12	16	20	7	10	12	13	10	13	15	16
Nevada	5	10	13	17	5	8	11	13	4	7	9	11
New Mexico	5	9	13	16	5	8	10	12	5	7	9	11
Utah	7	12	16	20	8	12	14	15	10	13	15	16
Wyoming	8	14	19	23	9	13	15	17	11	15	17	19
Regional Weighted Average	**6**	**11**	**15**	**18**	**6**	**10**	**12**	**13**	**7**	**10**	**12**	**13**
West - Pacific												
Alaska	9	16	20	25	9	12	13	14	8	11	12	14
California - 1	4	7	10	13	4	6	8	9	4	6	8	10
California - 2	6	11	14	17	5	8	9	11	5	8	10	11
California - 3	4	8	11	13	3	5	7	9	4	6	8	9
Hawaii	4	7	10	13	4	6	8	10	3	6	8	9
Oregon	9	14	18	22	9	12	14	15	8	11	13	15
Washington	11	17	22	27	9	13	16	17	8	12	15	16
Regional Weighted Average	**6**	**10**	**13**	**16**	**5**	**8**	**9**	**11**	**5**	**8**	**9**	**11**
U.S. weighted average	**7**	**12**	**15**	**19**	**6**	**9**	**11**	**13**	**6**	**9**	**11**	**13**

Source: Analysis by Clean-Power Research and NCI

NAVIGANT CONSULTING

The methodology to calculate roof area available for PV systems is:



NAVIGANT CONSULTING

Key sources of data and assumption used for the analysis of total roof area available for PV systems:

Key Sources of Data

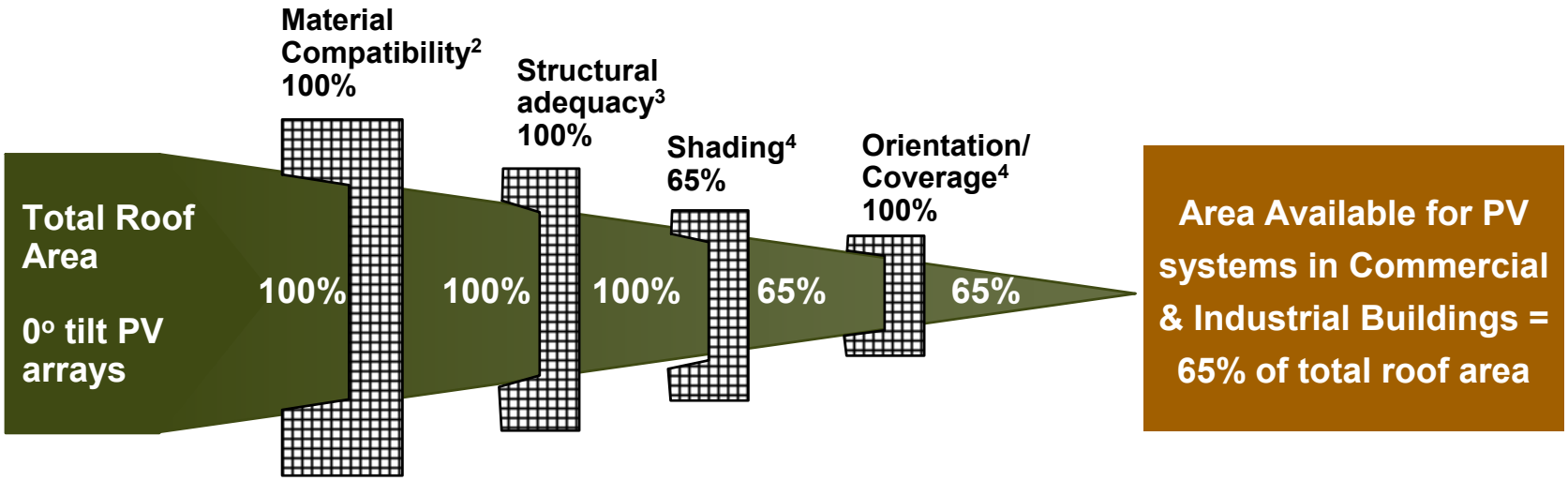
- EIA's Residential Energy Consumption Survey (RECS) 2001
- EIA's Commercial Buildings Energy Consumption Survey (CBECS) 1999
- Building data used by the EIA for its Annual Energy Outlook 2003, made available to NCI
  - Commercial buildings: Total floor space forecast by Census region for each year till 2025
  - Residential buildings: Total number of buildings by type of building for each year till 2025; Total floor space for each year till 2025

Key Assumptions / Analysis Notes

- Building characteristics (distribution by number of floors or bedrooms, average number of floors, etc) remain the same as provided in the 2001 RECS and 1999 CBECS.
- Percent of roof space available due to solar access issues remains the same over time (though it is likely that some newly constructed buildings may take into account solar access issues, where possible and viable).
- Commercial roof space available for PV was distributed into space available for small/medium PV systems and large PV systems by taking into account the following:
  - Number of buildings distributed by range of roof area per building
  - Size of PV system that can be installed by range of roof area per building

NAVIGANT CONSULTING

The roof space available in commercial buildings for PV installations is around 65% of total roof area[1].

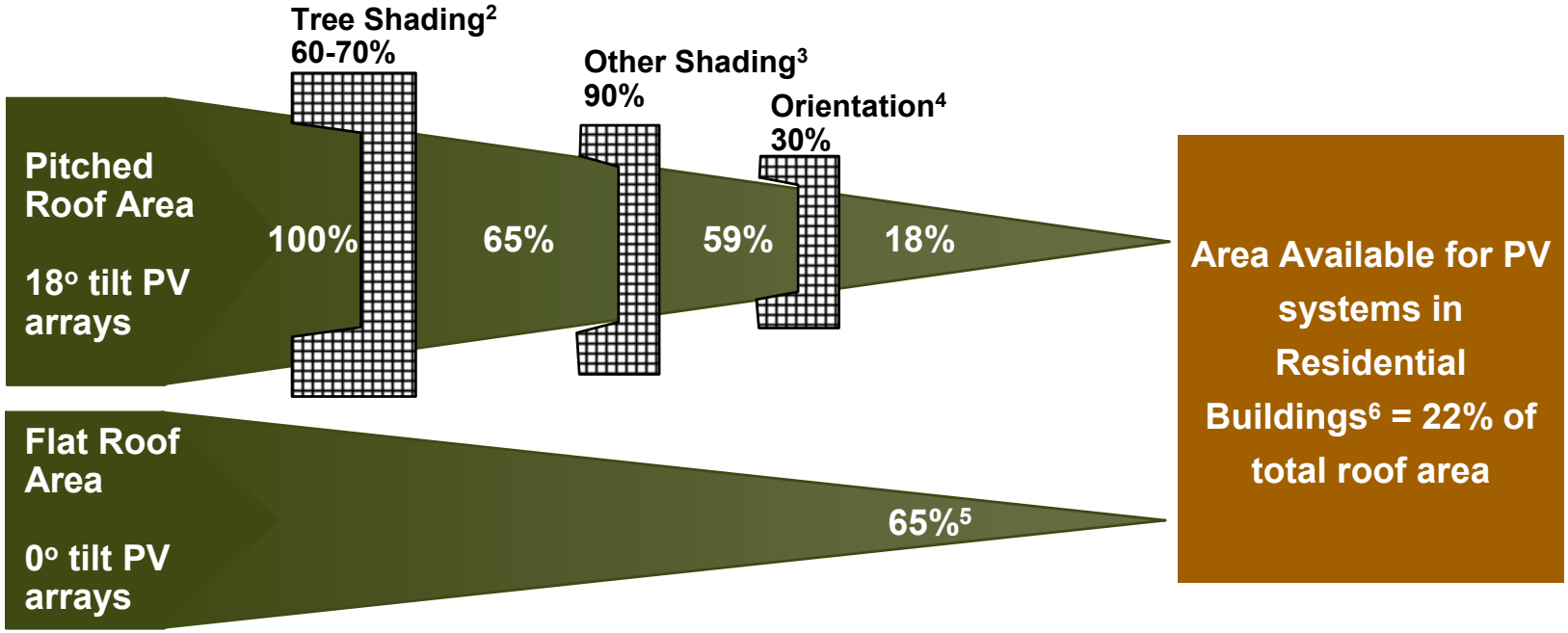


1) Includes roof space over enclosed garages.
2) Roofing material is predominantly built up asphalt or EPDM, both of which are suitable for PV and therefore there are no compatibility issues for flat roof buildings.
3) Structural adequacy is a function of roof structure (type of roof, decking and bar joists used ,etc.) and building code requirements (wind loading, snow loading which increases the live load requirements). For most buildings, this is not expected to be an issue.
4) An estimated 5% of commercial building roofing space is occupied by HVAC and other structures. Small obstructions create problems with mechanical array placement while large obstructions share areas up to 7x that of the footprint. Hence, around 35% of roof area is considered to be unavailable due to shading. In some commercial buildings such as shopping center, rooftops tend to be geometrically more complex than in other buildings and the percentage of unavailable space may be slightly higher.
5) Flat arrays are assumed. If tilted arrays were assumed, then more space would be required per PV panel due to panel shading issues, which would reduce the roof space available.

Note: The data is based on a study conducted by the Navigant Consulting team while at Arthur D. Little (data is proprietary to Navigant Consulting). New construction may have higher availability, as solar access issues are taken into account in designing new buildings.

NAVIGANT CONSULTING

The roof space available in residential buildings for PV installations is around 22% of total roof area[1].



1) Includes roof space over enclosed garages.
2) Roof area available due to tree shading is around 60% for single homes and higher at 70% for townhouses and other residential buildings. Closely packed homes in high density neighborhoods allow little room for large trees to grow and shade roofs, compared to larger homes in low density neighborhoods.
3) Other shading may be due to chimneys, vent stacks and other roof obstructions.
4) Based on assumptions made for single homes, which account for 70% of the building stock in the country. Assume that orientations from southeast clockwise around to west are appropriate for PV installations. For gable ended roofs with one long ridge line, assume that one of the pitched surfaces will face in the proper direction for 75% of the residences. If each surface is half the roof, 38% of the roof area can accommodate PV arrays. For hip roof buildings, one of four roof area will be facing in the right direction, or 25% of the roof area. The average of 38% and 25% is around 30%, which is what is assumed as the percentage of roof area with acceptable orientation.
5) See analysis of roof area availability for flat roof buildings on previous page.
6) Assumes single home and 2-4 unit apartments have pitched roof, which accounts for 92% of total roof space, the balance 8% being flat roof space on 5+ unit apartments and mobile homes.

Note: The data is based on a study conducted by the Navigant Consulting team while at Arthur D. Little (data is proprietary to Navigant Consulting). New construction may have higher availability, as solar access issues are taken into account in designing new buildings.

Estimated roof area available for PV in 2025, by state and segment:

2025 Roof Available for PV (Mln. Sq.ft)							
State	Residential Total	Commercial: Small/Med	Commercial: Large	Commercial Total	Total	% share of U.S Total	% share of Residential
Midwest - East North Central							
Illinois	1,709	1,133	113	1,246	2,955	3%	58%
Indiana	917	670	67	737	1,654	2%	55%
Michigan	1,477	1,055	105	1,160	2,636	3%	56%
Ohio	1,715	1,269	127	1,396	3,110	4%	55%
Wisconsin	842	642	64	706	1,548	2%	54%
Regional subtotal	**6,659**	**4,769**	**476**	**5,244**	**11,903**	**14%**	**56%**
Midwest - West North Central							
Iowa	483	365	38	402	886	1%	55%
Kansas	442	402	41	443	885	1%	50%
Minnesota	804	487	50	537	1,341	2%	60%
Missouri	953	679	70	749	1,702	2%	56%
Nebraska	283	258	27	284	567	1%	50%
North Dakota	113	100	10	110	223	0%	51%
South Dakota	127	109	11	120	247	0%	51%
Regional subtotal	**3,205**	**2,399**	**248**	**2,646**	**5,851**	**7%**	**55%**
NorthEast - Middle Atlantic							
New Jersey	895	544	69	613	1,508	2%	59%
New York -1	508	318	40	358	867	1%	59%
New York -2	1,017	636	81	716	1,733	2%	59%
New York -3	358	224	28	252	610	1%	59%
Pennsylvania	1,424	1,045	132	1,177	2,601	3%	55%
Regional subtotal	**4,202**	**2,766**	**351**	**3,117**	**7,319**	**9%**	**57%**
NorthEast - New England							
Connecticut	410	233	37	269	679	1%	60%
Maine	193	128	20	149	342	0%	56%
Massachusetts	740	568	89	657	1,397	2%	53%
New Hampshire	160	150	24	173	334	0%	48%
Rhode Island	123	83	13	97	219	0%	56%
Vermont	84	73	12	85	169	0%	50%
Regional subtotal	**1,710**	**1,235**	**194**	**1,430**	**3,140**	**4%**	**54%**
South - East South Central							
Alabama	964	698	327	1,024	1,988	2%	48%
Kentucky	887	527	247	774	1,661	2%	53%
Mississippi	587	413	193	606	1,193	1%	49%
Tennessee	1,205	848	397	1,246	2,451	3%	49%
Regional subtotal	**3,642**	**2,486**	**1,164**	**3,650**	**7,293**	**9%**	**50%**

2025 Roof Available for PV (Mln. Sq.ft)							
State	Residential Total	Commercial: Small/Med	Commercial: Large	Commercial Total	Total	% share of U.S Total	% share of Residential
South - South Atlantic							
Delaware	137	106	13	119	256	0%	54%
Florida	2,942	2,387	297	2,684	5,626	7%	52%
Georgia	1,398	1,122	140	1,262	2,660	3%	53%
Maryland	808	579	72	651	1,459	2%	55%
North Carolina	1,463	1,388	173	1,560	3,024	4%	48%
South Carolina	718	672	84	755	1,473	2%	49%
Virginia	1,129	824	103	927	2,055	2%	55%
Washington, DC	78	72	9	81	159	0%	49%
West Virginia	330	316	39	355	685	1%	48%
Regional subtotal	**9,004**	**7,465**	**929**	**8,394**	**17,397**	**21%**	**52%**
South - West South Central							
Arkansas	582	312	74	386	969	1%	60%
Louisiana	894	469	112	581	1,474	2%	61%
Oklahoma	747	436	104	540	1,287	2%	58%
Texas	4,086	2,410	575	2,985	7,071	8%	58%
Regional subtotal	**6,309**	**3,627**	**865**	**4,492**	**10,801**	**13%**	**58%**
West - Mountain							
Arizona	845	684	102	786	1,632	2%	52%
Colorado	759	773	116	888	1,647	2%	46%
Idaho	226	299	45	344	570	1%	40%
Montana	171	243	36	280	451	1%	38%
Nevada	344	363	54	417	762	1%	45%
New Mexico	305	345	52	397	702	1%	43%
Utah	321	275	41	316	637	1%	50%
Wyoming	93	157	24	181	274	0%	34%
Regional subtotal	**3,065**	**3,139**	**470**	**3,609**	**6,674**	**8%**	**46%**
West - Pacific							
Alaska	103	109	15	124	227	0%	45%
California -1	2,346	1,992	281	2,273	4,620	5%	51%
California -2	261	221	31	253	513	1%	51%
California -3	2,607	2,214	312	2,526	5,133	6%	51%
Hawaii	165	156	22	178	343	0%	48%
Oregon	640	598	84	683	1,323	2%	48%
Washington	1,087	807	114	921	2,007	2%	54%
Regional subtotal	**7,210**	**6,097**	**860**	**6,957**	**14,166**	**17%**	**51%**
Total	**45,005**	**33,982**	**5,556**	**39,538**	**84,544**	**100%**	**53%**

Source: Analysis by Clean-Power Research and NCI
Note: Commercial Total = Total of Commercial Small/Medium and Commercial Large

Estimated roof area available for PV in 2010, by state and segment:

2010 Roof Available for PV (Mln. Sq.ft)							
State	Residential Total	Commercial: Small/med	Commercial : Large	Commercial Total	Total	% share of U.S Total	% share of Residential
Midwest - East North Central							
Illinois	1,428	994	99	1,093	2,521	4%	57%
Indiana	766	588	59	647	1,413	2%	54%
Michigan	1,234	925	92	1,018	2,252	3%	55%
Ohio	1,433	1,114	111	1,225	2,658	4%	54%
Wisconsin	704	563	56	620	1,323	2%	53%
Regional subtotal	**5,565**	**4,184**	**417**	**4,602**	**10,167**	**15%**	**55%**
Midwest - West North Central							
Iowa	404	321	33	354	757	1%	53%
Kansas	369	353	36	389	759	1%	49%
Minnesota	671	428	44	472	1,143	2%	59%
Missouri	795	597	62	659	1,454	2%	55%
Nebraska	236	226	23	250	486	1%	49%
North Dakota	94	88	9	97	191	0%	49%
South Dakota	106	96	10	106	212	0%	50%
Regional subtotal	**2,676**	**2,109**	**218**	**2,326**	**5,002**	**7%**	**53%**
NorthEast - Middle Atlantic							
New Jersey	749	515	65	581	1,330	2%	56%
New York -1	426	301	38	339	764	1%	56%
New York -2	851	602	76	678	1,529	2%	56%
New York -3	299	212	27	239	538	1%	56%
Pennsylvania	1,192	989	125	1,114	2,306	3%	52%
Regional subtotal	**3,517**	**2,618**	**332**	**2,950**	**6,467**	**9%**	**54%**
NorthEast - New England							
Connecticut	343	205	32	237	580	1%	59%
Maine	161	113	18	131	292	0%	55%
Massachusetts	619	499	78	577	1,197	2%	52%
New Hampshire	134	132	21	152	287	0%	47%
Rhode Island	103	73	12	85	187	0%	55%
Vermont	70	65	10	75	145	0%	48%
Regional subtotal	**1,431**	**1,086**	**171**	**1,257**	**2,687**	**4%**	**53%**
South - East South Central							
Alabama	805	570	267	838	1,643	2%	49%
Kentucky	741	431	202	633	1,374	2%	54%
Mississippi	490	338	158	496	986	1%	50%
Tennessee	1,006	694	325	1,019	2,025	3%	50%
Regional subtotal	**3,043**	**2,032**	**952**	**2,984**	**6,027**	**9%**	**50%**

2010 Roof Available for PV (Mln. Sq.ft)							
State	Residential Total	Commercial: Small/med	Commercial : Large	Commercial Total	Total	% share of U.S Total	% share of Residential
South - South Atlantic							
Delaware	115	76	10	86	201	0%	57%
Florida	2,457	1,726	215	1,941	4,398	6%	56%
Georgia	1,168	812	101	913	2,080	3%	56%
Maryland	675	418	52	471	1,145	2%	59%
North Carolina	1,222	1,003	125	1,128	2,351	3%	52%
South Carolina	600	486	60	546	1,146	2%	52%
Virginia	942	596	74	670	1,613	2%	58%
Washington, DC	65	52	6	58	124	0%	53%
West Virginia	276	228	28	257	533	1%	52%
Regional subtotal	**7,520**	**5,398**	**672**	**6,070**	**13,590**	**20%**	**55%**
South - West South Central							
Arkansas	487	281	67	349	835	1%	58%
Louisiana	747	423	101	524	1,271	2%	59%
Oklahoma	624	394	94	487	1,111	2%	56%
Texas	3,414	2,175	519	2,694	6,108	9%	56%
Regional subtotal	**5,271**	**3,274**	**781**	**4,054**	**9,325**	**13%**	**57%**
West - Mountain							
Arizona	707	474	71	545	1,252	2%	56%
Colorado	635	536	80	616	1,251	2%	51%
Idaho	189	207	31	238	427	1%	44%
Montana	143	169	25	194	337	0%	42%
Nevada	288	252	38	290	578	1%	50%
New Mexico	255	239	36	275	530	1%	48%
Utah	268	191	29	219	488	1%	55%
Wyoming	78	109	16	125	203	0%	38%
Regional subtotal	**2,563**	**2,177**	**326**	**2,503**	**5,066**	**7%**	**51%**
West - Pacific							
Alaska	86	79	11	90	176	0%	49%
California -1	1,963	1,445	204	1,649	3,612	5%	54%
California -2	218	161	23	183	401	1%	54%
California -3	2,181	1,606	226	1,833	4,014	6%	54%
Hawaii	138	113	16	129	267	0%	52%
Oregon	536	434	61	495	1,031	1%	52%
Washington	909	585	83	668	1,577	2%	58%
Regional subtotal	**6,032**	**4,423**	**624**	**5,047**	**11,078**	**16%**	**54%**
U.S Total	**37,616**	**27,302**	**4,492**	**31,793**	**69,409**	**100%**	**54%**

Note: Commercial Total = Total of Commercial Small/Medium and Commercial Large

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Technical market for PV (MWp) in 2025 – by state and segment.

2025 Technical Ultimate Potential (MWp)					
State	Residential Total	Commercial Total	Total	% share of U.S Total	% share of Residential
Midwest - East North Central					
Illinois	20,976	15,285	36,261	3%	58%
Indiana	11,248	9,048	20,296	2%	55%
Michigan	18,121	14,232	32,353	3%	56%
Ohio	21,045	17,126	38,171	4%	55%
Wisconsin	10,332	8,665	18,997	2%	54%
Regional subtotal	**81,722**	**64,356**	**146,078**	**14%**	**56%**
Midwest - West North Central					
Iowa	5,931	4,939	10,870	1%	55%
Kansas	5,429	5,436	10,865	1%	50%
Minnesota	9,864	6,592	16,456	2%	60%
Missouri	11,690	9,193	20,882	2%	56%
Nebraska	3,475	3,487	6,961	1%	50%
North Dakota	1,383	1,353	2,736	0%	51%
South Dakota	1,555	1,478	3,032	0%	51%
Regional subtotal	**39,326**	**32,477**	**71,804**	**7%**	**55%**
NorthEast - Middle Atlantic					
New Jersey	10,985	7,527	18,511	2%	59%
New York -1	6,240	4,395	10,635	1%	59%
New York -2	12,480	8,790	21,270	2%	59%
New York -3	4,391	3,093	7,484	1%	59%
Pennsylvania	17,473	14,445	31,917	3%	55%
Regional subtotal	**51,568**	**38,249**	**89,817**	**9%**	**57%**
NorthEast - New England					
Connecticut	5,029	3,306	8,335	1%	60%
Maine	2,368	1,824	4,192	0%	56%
Massachusetts	9,083	8,062	17,144	2%	53%
New Hampshire	1,969	2,126	4,095	0%	48%
Rhode Island	1,504	1,185	2,688	0%	56%
Vermont	1,030	1,043	2,073	0%	50%
Regional subtotal	**20,983**	**17,545**	**38,528**	**4%**	**54%**
South - East South Central					
Alabama	11,828	12,573	24,401	2%	48%
Kentucky	10,884	9,495	20,379	2%	53%
Mississippi	7,201	7,441	14,642	1%	49%
Tennessee	14,785	15,288	30,073	3%	49%
Regional subtotal	**44,699**	**44,797**	**89,495**	**9%**	**50%**

2025 Technical Ultimate Potential (MWp)					
State	Residential Total	Commercial Total	Total	% share of U.S Total	% share of Residential
South - South Atlantic					
Delaware	1,685	1,459	3,144	0%	54%
Florida	36,103	32,943	69,046	7%	52%
Georgia	17,159	15,487	32,646	3%	53%
Maryland	9,915	7,985	17,900	2%	55%
North Carolina	17,959	19,147	37,106	4%	48%
South Carolina	8,810	9,267	18,077	2%	49%
Virginia	13,849	11,376	25,225	2%	55%
Washington, DC	958	990	1,948	0%	49%
West Virginia	4,055	4,354	8,409	1%	48%
Regional subtotal	**110,493**	**103,007**	**213,501**	**21%**	**52%**
South - West South Central					
Arkansas	7,146	4,740	11,886	1%	60%
Louisiana	10,966	7,124	18,090	2%	61%
Oklahoma	9,162	6,627	15,790	2%	58%
Texas	50,149	36,630	86,779	8%	58%
Regional subtotal	**77,423**	**55,121**	**132,544**	**13%**	**58%**
West - Mountain					
Arizona	10,375	9,650	20,025	2%	52%
Colorado	9,314	10,901	20,215	2%	46%
Idaho	2,773	4,216	6,989	1%	40%
Montana	2,098	3,433	5,531	1%	38%
Nevada	4,227	5,123	9,350	1%	45%
New Mexico	3,740	4,872	8,612	1%	43%
Utah	3,941	3,877	7,818	1%	50%
Wyoming	1,146	2,217	3,364	0%	34%
Regional subtotal	**37,614**	**44,289**	**81,904**	**8%**	**46%**
West - Pacific					
Alaska	1,268	1,522	2,790	0%	45%
California -1	28,794	27,899	56,693	5%	51%
California -2	3,199	3,100	6,299	1%	51%
California -3	31,993	30,999	62,992	6%	51%
Hawaii	2,026	2,179	4,206	0%	48%
Oregon	7,859	8,376	16,236	2%	48%
Washington	13,337	11,297	24,633	2%	54%
Regional subtotal	**88,477**	**85,371**	**173,848**	**17%**	**51%**
Total	**552,307**	**485,213**	**1,037,519**	**100%**	**53%**

Note: Commercial Total = Total of Commercial Small/Medium and Commercial Large

Technical market for PV (MWp) in 2010 – by state and segment.

2010 Technical Ultimate Potential (MWp)					
State	Residential Total	Commercial: Total	Total	% share of U.S Total	% share of Residential
Midwest - East North Central					
Illinois	14,650	11,209	25,859	4%	57%
Indiana	7,856	6,635	14,492	2%	54%
Michigan	12,657	10,437	23,094	3%	55%
Ohio	14,698	12,559	27,258	4%	54%
Wisconsin	7,216	6,354	13,571	2%	53%
Regional subtotal	**57,078**	**47,195**	**104,273**	**15%**	**55%**
Midwest - West North Central					
Iowa	4,139	3,629	7,767	1%	53%
Kansas	3,789	3,994	7,782	1%	49%
Minnesota	6,883	4,843	11,726	2%	59%
Missouri	8,157	6,754	14,911	2%	55%
Nebraska	2,425	2,562	4,986	1%	49%
North Dakota	965	994	1,959	0%	49%
South Dakota	1,085	1,086	2,171	0%	50%
Regional subtotal	**27,443**	**23,860**	**51,303**	**7%**	**53%**
NorthEast - Middle Atlantic					
New Jersey	7,683	5,954	13,636	2%	56%
New York - 1	4,364	3,476	7,841	1%	56%
New York - 2	8,728	6,953	15,681	2%	56%
New York - 3	3,071	2,446	5,517	1%	56%
Pennsylvania	12,220	11,426	23,646	3%	52%
Regional subtotal	**36,066**	**30,255**	**66,321**	**9%**	**54%**
NorthEast - New England					
Connecticut	3,517	2,428	5,945	1%	59%
Maine	1,656	1,340	2,996	0%	55%
Massachusetts	6,351	5,922	12,273	2%	52%
New Hampshire	1,377	1,562	2,938	0%	47%
Rhode Island	1,052	870	1,922	0%	55%
Vermont	720	766	1,486	0%	48%
Regional subtotal	**14,672**	**12,889**	**27,561**	**4%**	**53%**
South - East South Central					
Alabama	8,258	8,591	16,849	2%	49%
Kentucky	7,599	6,488	14,087	2%	54%
Mississippi	5,028	5,084	10,112	1%	50%
Tennessee	10,322	10,446	20,768	3%	50%
Regional subtotal	**31,207**	**30,609**	**61,815**	**9%**	**50%**

2010 Technical Ultimate Potential (MWp)					
State	Residential Total	Commercial: Total	Total	% share of U.S Total	% share of Residential
South - South Atlantic					
Delaware	1,176	882	2,058	0%	57%
Florida	25,198	19,910	45,109	6%	56%
Georgia	11,977	9,360	21,337	3%	56%
Maryland	6,920	4,826	11,746	2%	59%
North Carolina	12,535	11,572	24,107	3%	52%
South Carolina	6,149	5,601	11,750	2%	52%
Virginia	9,666	6,875	16,542	2%	58%
Washington, DC	669	598	1,267	0%	53%
West Virginia	2,830	2,631	5,462	1%	52%
Regional subtotal	**77,120**	**62,256**	**139,376**	**20%**	**55%**
South - West South Central					
Arkansas	4,990	3,575	8,565	1%	58%
Louisiana	7,657	5,374	13,031	2%	59%
Oklahoma	6,398	4,999	11,397	2%	56%
Texas	35,016	27,631	62,647	9%	56%
Regional subtotal	**54,061**	**41,580**	**95,640**	**13%**	**57%**
West - Mountain					
Arizona	7,249	5,593	12,843	2%	56%
Colorado	6,508	6,318	12,826	2%	51%
Idaho	1,938	2,444	4,381	1%	44%
Montana	1,466	1,990	3,456	0%	42%
Nevada	2,954	2,969	5,923	1%	50%
New Mexico	2,613	2,824	5,437	1%	48%
Utah	2,753	2,247	5,001	1%	55%
Wyoming	801	1,285	2,086	0%	38%
Regional subtotal	**26,283**	**25,671**	**51,953**	**7%**	**51%**
West - Pacific					
Alaska	887	923	1,809	0%	49%
California - 1	20,132	16,915	37,047	5%	54%
California - 2	2,237	1,879	4,116	1%	54%
California - 3	22,369	18,794	41,163	6%	54%
Hawaii	1,417	1,321	2,738	0%	52%
Oregon	5,495	5,078	10,573	1%	52%
Washington	9,324	6,849	16,173	2%	58%
Regional subtotal	**61,860**	**51,760**	**113,620**	**16%**	**54%**
U. S. Total	**385,790**	**326,074**	**711,864**	**100%**	**54%**

Note: Commercial Total = Total of Commercial Small/Medium and Commercial Large

Potential annual demand for grid-connected PV in 2010 for residential segment, by state and installed system price scenario (1 of 2).

Residential: Demand in 2010								
State	Annual demand (MWp) in 2010				% share of annual demand in 2010			
System price ($/Wpdc) >>	$1.25	$2.50	$3.75	$5.30	$1.25	$2.50	$3.75	$5.30
Midwest - East North Central								
Illinois	150	16	8	4	2.8%	1.7%	2.8%	2.7%
Indiana	11	4	1	0	0.2%	0.4%	0.5%	0.0%
Michigan	140	15	8	4	2.6%	1.6%	2.6%	2.7%
Ohio	274	22	13	7	5.1%	2.3%	4.3%	4.6%
Wisconsin	80	8	4	3	1.5%	0.9%	1.5%	1.6%
Regional sub-total	**654**	**65**	**34**	**19**	**12.2%**	**6.8%**	**11.6%**	**11.6%**
Midwest - West North Central								
Iowa	55	5	3	2	1.0%	0.5%	0.9%	1.0%
Kansas	25	3	2	1	0.5%	0.3%	0.6%	0.5%
Minnesota	60	7	4	2	1.1%	0.7%	1.2%	1.3%
Missouri	52	7	4	2	1.0%	0.7%	1.2%	0.9%
Nebraska	15	2	1	0	0.3%	0.2%	0.3%	0.3%
North Dakota	6	1	0	0	0.1%	0.1%	0.2%	0.2%
South Dakota	8	1	0	0	0.1%	0.1%	0.2%	0.1%
Regional sub-total	**220**	**25**	**14**	**7**	**4.1%**	**2.7%**	**4.6%**	**4.3%**
NorthEast - Middle Atlantic								
New Jersey	152	23	8	4	2.8%	2.4%	2.6%	2.7%
New York -1	62	6	3	2	1.2%	0.6%	0.9%	1.1%
New York -2	226	62	12	7	4.2%	6.4%	4.0%	4.6%
New York -3	68	16	4	2	1.3%	1.7%	1.2%	1.2%
Pennsylvania	106	12	6	3	2.0%	1.2%	2.0%	1.7%
Regional sub-total	**613**	**118**	**32**	**18**	**11.5%**	**12.3%**	**10.8%**	**11.3%**
NorthEast - New England								
Connecticut	50	5	2	1	0.9%	0.5%	0.8%	0.9%
Maine	35	6	2	1	0.6%	0.7%	0.6%	0.6%
Massachusetts	156	36	8	4	2.9%	3.7%	2.6%	2.6%
New Hampshire	27	2	1	1	0.5%	0.2%	0.4%	0.4%
Rhode Island	21	2	1	1	0.4%	0.2%	0.3%	0.4%
Vermont	13	1	1	0	0.3%	0.1%	0.2%	0.2%
Regional sub-total	**302**	**51**	**14**	**8**	**5.7%**	**5.4%**	**4.9%**	**5.1%**
South - East South Central								
Alabama	78	8	4	2	1.5%	0.8%	1.4%	1.4%
Kentucky	35	5	3	1	0.6%	0.5%	1.0%	0.5%
Mississippi	30	4	2	1	0.6%	0.4%	0.7%	0.5%
Tennessee	73	9	5	2	1.4%	0.9%	1.6%	1.1%
Regional sub-total	**216**	**26**	**14**	**6**	**4.0%**	**2.7%**	**4.7%**	**3.5%**

Potential annual demand for grid-connected PV in 2010 for residential segment, by state and installed system price scenario (2 of 2).

Residential: Demand in 2010								
State	Annual demand (MWp) in 2010				% share of annual demand in 2010			
System price ($/Wpdc) >>	$1.25	$2.50	$3.75	$5.30	$1.25	$2.50	$3.75	$5.30
South - South Atlantic								
Delaware	15	1	1	0	0.3%	0.2%	0.2%	0.3%
Florida	385	34	17	10	7.2%	3.5%	5.6%	6.3%
Georgia	123	13	7	4	2.3%	1.4%	2.3%	2.5%
Maryland	65	7	4	2	1.2%	0.8%	1.3%	1.3%
North Carolina	165	15	8	5	3.1%	1.6%	2.6%	3.0%
South Carolina	87	8	4	3	1.6%	0.8%	1.4%	1.6%
Virginia	91	11	5	3	1.7%	1.1%	1.8%	1.8%
Washington, DC	10	1	0	0	0.2%	0.1%	0.2%	0.2%
West Virginia	4	1	1	0	0.1%	0.2%	0.2%	0.0%
Regional sub-total	**946**	**92**	**46**	**27**	**17.7%**	**9.6%**	**15.7%**	**17.0%**
South - West South Central								
Arkansas	47	5	3	1	0.9%	0.5%	0.9%	0.9%
Louisiana	125	11	6	4	2.3%	1.2%	2.1%	2.3%
Oklahoma	41	5	3	1	0.8%	0.5%	1.0%	0.8%
Texas	387	41	20	11	7.2%	4.2%	6.7%	6.7%
Regional sub-total	**600**	**62**	**32**	**17**	**11.2%**	**6.4%**	**10.7%**	**10.7%**
West - Mountain								
Arizona	179	44	9	5	3.3%	4.5%	3.0%	3.0%
Colorado	61	7	3	2	1.2%	0.7%	1.2%	1.1%
Idaho	13	2	1	0	0.2%	0.2%	0.3%	0.3%
Montana	14	2	1	1	0.3%	0.2%	0.3%	0.3%
Nevada	58	7	3	2	1.1%	0.7%	0.9%	1.0%
New Mexico	52	10	3	2	1.0%	1.0%	0.9%	1.0%
Utah	28	3	2	1	0.5%	0.3%	0.5%	0.6%
Wyoming	5	1	0	0	0.1%	0.1%	0.1%	0.1%
Regional sub-total	**411**	**74**	**22**	**12**	**7.7%**	**7.7%**	**7.3%**	**7.4%**
West - Pacific								
Alaska	4	1	0	0	0.1%	0.1%	0.1%	0.0%
California - 1	642	206	46	22	12.0%	21.5%	15.6%	13.7%
California - 2	37	3	2	1	0.7%	0.3%	0.6%	0.7%
California - 3	608	211	32	21	11.4%	22.0%	10.9%	13.2%
Hawaii	45	14	3	1	0.8%	1.5%	1.1%	0.9%
Oregon	33	4	2	1	0.6%	0.5%	0.8%	0.7%
Washington	13	5	2	0	0.3%	0.5%	0.5%	0.0%
Regional sub-total	**1,382**	**445**	**88**	**47**	**25.9%**	**46.4%**	**29.7%**	**29.2%**
U. S. Total	**5,344**	**958**	**296**	**160**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

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Potential annual demand for grid-connected PV in 2010 for commercial segment, by state and installed system price scenario (1 of 2).

Commercial Total:Demand in 2010								
State	Annual demand (MWp) in 2010				% share of annual demand in 2010			
System price ($/Wpdc) >>	$ 1.00-1.10	$ 2.00- $ 2.20	$ 3.00-3.30	$ 4.25-4.65	$ 1.00-1.10	$ 2.00- $ 2.20	$ 3.00-3.30	$ 4.25-4.65
Midwest - East North Central								
Illinois	158	22	13	10	2.7%	1.1%	1.5%	1.9%
Indiana	47	8	6	4	0.8%	0.4%	0.7%	0.8%
Michigan	156	26	12	9	2.6%	1.3%	1.4%	1.7%
Ohio	244	78	18	15	4.1%	4.0%	2.1%	2.9%
Wisconsin	88	24	8	6	1.5%	1.2%	0.9%	1.3%
Regional sub-total	**694**	**157**	**57**	**44**	**11.7%**	**8.1%**	**6.6%**	**8.7%**
Midwest - West North Central								
Iowa	50	16	5	4	0.8%	0.8%	0.6%	0.8%
Kansas	20	4	3	2	0.3%	0.2%	0.3%	0.5%
Minnesota	52	7	6	5	0.9%	0.4%	0.7%	0.9%
Missouri	60	10	6	5	1.0%	0.5%	0.8%	1.0%
Nebraska	17	3	3	2	0.3%	0.2%	0.3%	0.4%
North Dakota	9	1	1	1	0.1%	0.1%	0.1%	0.2%
South Dakota	9	1	1	1	0.1%	0.1%	0.1%	0.1%
Regional sub-total	**216**	**44**	**25**	**20**	**3.6%**	**2.2%**	**2.9%**	**3.9%**
NorthEast - Middle Atlantic								
New Jersey	105	35	8	7	1.8%	1.8%	1.0%	1.3%
New York -1	66	23	6	4	1.1%	1.2%	0.7%	0.8%
New York -2	156	61	21	9	2.6%	3.2%	2.5%	1.8%
New York -3	58	24	12	4	1.0%	1.2%	1.5%	0.8%
Pennsylvania	143	38	14	11	2.4%	2.0%	1.6%	2.2%
Regional sub-total	**529**	**182**	**62**	**35**	**8.9%**	**9.4%**	**7.3%**	**6.9%**
NorthEast - New England								
Connecticut	37	12	3	3	0.6%	0.6%	0.4%	0.5%
Maine	28	9	3	2	0.5%	0.5%	0.3%	0.3%
Massachusetts	157	76	34	12	2.6%	3.9%	4.0%	2.4%
New Hampshire	25	7	2	2	0.4%	0.4%	0.2%	0.3%
Rhode Island	18	7	2	1	0.3%	0.4%	0.2%	0.2%
Vermont	13	4	1	1	0.2%	0.2%	0.1%	0.2%
Regional sub-total	**278**	**116**	**45**	**20**	**4.7%**	**6.0%**	**5.3%**	**4.0%**
South - East South Central								
Alabama	138	32	11	9	2.3%	1.6%	1.3%	1.7%
Kentucky	57	9	7	6	1.0%	0.5%	0.8%	1.1%
Mississippi	48	7	5	4	0.8%	0.4%	0.6%	0.8%
Tennessee	171	43	14	11	2.9%	2.2%	1.7%	2.2%
Regional sub-total	**413**	**90**	**38**	**29**	**6.9%**	**4.6%**	**4.4%**	**5.8%**

Note: Commercial Total = Total of Commercial Small/Medium and Commercial Large

Potential annual demand for grid-connected PV in 2010 for commercial segment, by state and installed system price scenario (2 of 2).

Commercial Total:Demand in 2010								
State	Annual demand (MWp) in 2010				% share of annual demand in 2010			
System price ($/Wpdc) >>	$ 1.00-1.10	$ 2.00- $ 2.20	$ 3.00-3.30	$ 4.25-4.65	$ 1.00-1.10	$ 2.00- $ 2.20	$ 3.00-3.30	$ 4.25-4.65
South - South Atlantic								
Delaware	20	6	2	1	0.3%	0.3%	0.2%	0.2%
Florida	452	136	33	26	7.6%	7.0%	3.9%	5.1%
Georgia	236	91	24	14	4.0%	4.7%	2.8%	2.7%
Maryland	79	12	7	5	1.3%	0.6%	0.8%	1.1%
North Carolina	265	82	20	16	4.5%	4.2%	2.3%	3.2%
South Carolina	99	27	8	6	1.7%	1.4%	1.0%	1.2%
Virginia	76	11	9	6	1.3%	0.6%	1.0%	1.3%
Washington, DC	13	4	1	1	0.2%	0.2%	0.1%	0.2%
West Virginia	19	4	3	2	0.3%	0.2%	0.4%	0.5%
Regional sub-total	**1,259**	**374**	**106**	**78**	**21.2%**	**19.3%**	**12.4%**	**15.4%**
South - West South Central								
Arkansas	31	5	4	3	0.5%	0.2%	0.4%	0.5%
Louisiana	97	30	7	6	1.6%	1.5%	0.9%	1.2%
Oklahoma	28	6	4	3	0.5%	0.3%	0.5%	0.6%
Texas	340	39	30	22	5.7%	2.0%	3.5%	4.4%
Regional sub-total	**496**	**79**	**45**	**34**	**8.4%**	**4.0%**	**5.2%**	**6.8%**
West - Mountain								
Arizona	133	43	10	8	2.2%	2.2%	1.2%	1.6%
Colorado	86	11	9	6	1.5%	0.6%	1.0%	1.3%
Idaho	39	8	4	3	0.7%	0.4%	0.4%	0.6%
Montana	30	5	3	2	0.5%	0.3%	0.3%	0.4%
Nevada	78	25	6	4	1.3%	1.3%	0.8%	0.8%
New Mexico	77	25	8	4	1.3%	1.3%	1.0%	0.9%
Utah	17	3	2	2	0.3%	0.2%	0.3%	0.3%
Wyoming	7	2	1	1	0.1%	0.1%	0.1%	0.2%
Regional sub-total	**468**	**122**	**43**	**31**	**7.9%**	**6.3%**	**5.1%**	**6.1%**
West - Pacific								
Alaska	7	1	1	1	0.1%	0.1%	0.1%	0.2%
California - 1	652	298	165	72	11.0%	15.3%	19.3%	14.3%
California - 2	53	20	8	3	0.9%	1.0%	0.9%	0.6%
California - 3	761	419	235	126	12.8%	21.6%	27.5%	24.9%
Hawaii	52	25	13	5	0.9%	1.3%	1.6%	1.0%
Oregon	32	7	5	4	0.5%	0.3%	0.6%	0.8%
Washington	32	8	5	4	0.5%	0.4%	0.6%	0.8%
Regional sub-total	**1,588**	**778**	**432**	**215**	**26.7%**	**40.1%**	**50.7%**	**42.5%**
U. S. Total	**5,941**	**1,942**	**852**	**506**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Note: Commercial Total = Total of Commercial Small/Medium and Commercial Large

Potential annual demand for total grid-connected PV in 2010, by state and installed system price scenario (1 of 2).

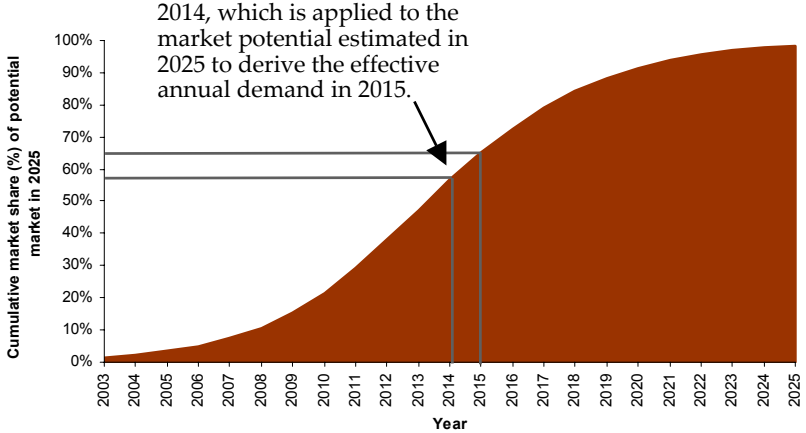
Grid Connected Total:Demand in 2010								
State	Annual demand (MWp) in 2010				% share of annual demand in 2010			
System price ($/Wpdc) >>	$ 1.00-1.25	$ 2.00- $ 2.50	$ 3.00-3.75	$ 4.25-5.30	$ 1.00-1.25	$ 2.00- $ 2.50	$ 3.00-3.75	$ 4.25-5.30
Midwest - East North Central								
Illinois	308	37	21	14	2.7%	1.3%	1.8%	2.1%
Indiana	58	12	7	4	0.5%	0.4%	0.6%	0.6%
Michigan	296	41	20	13	2.6%	1.4%	1.7%	2.0%
Ohio	518	100	31	22	4.6%	3.4%	2.7%	3.4%
Wisconsin	168	32	12	9	1.5%	1.1%	1.1%	1.4%
Regional sub-total	**1,348**	**222**	**91**	**62**	**11.9%**	**7.7%**	**7.9%**	**9.4%**
Midwest - West North Central								
Iowa	105	21	8	6	0.9%	0.7%	0.7%	0.9%
Kansas	45	7	5	3	0.4%	0.3%	0.4%	0.5%
Minnesota	111	14	9	7	1.0%	0.5%	0.8%	1.0%
Missouri	111	17	10	7	1.0%	0.6%	0.9%	1.0%
Nebraska	32	5	4	2	0.3%	0.2%	0.3%	0.4%
North Dakota	15	2	2	1	0.1%	0.1%	0.1%	0.2%
South Dakota	16	2	1	1	0.1%	0.1%	0.1%	0.1%
Regional sub-total	**436**	**69**	**38**	**27**	**3.9%**	**2.4%**	**3.3%**	**4.0%**
NorthEast - Middle Atlantic								
New Jersey	256	59	16	11	2.3%	2.0%	1.4%	1.7%
New York -1	128	28	9	6	1.1%	1.0%	0.8%	0.9%
New York -2	382	123	33	16	3.4%	4.2%	2.9%	2.5%
New York -3	126	40	16	6	1.1%	1.4%	1.4%	0.9%
Pennsylvania	249	50	20	14	2.2%	1.7%	1.7%	2.1%
Regional sub-total	**1,142**	**300**	**94**	**53**	**10.1%**	**10.3%**	**8.2%**	**8.0%**
NorthEast - New England								
Connecticut	87	17	6	4	0.8%	0.6%	0.5%	0.6%
Maine	62	15	4	3	0.6%	0.5%	0.4%	0.4%
Massachusetts	314	112	42	16	2.8%	3.9%	3.7%	2.5%
New Hampshire	52	9	3	2	0.5%	0.3%	0.3%	0.3%
Rhode Island	39	8	3	2	0.3%	0.3%	0.2%	0.3%
Vermont	26	5	2	1	0.2%	0.2%	0.1%	0.2%
Regional sub-total	**580**	**167**	**60**	**28**	**5.1%**	**5.8%**	**5.2%**	**4.3%**
South - East South Central								
Alabama	216	40	16	11	1.9%	1.4%	1.4%	1.7%
Kentucky	91	14	10	6	0.8%	0.5%	0.9%	1.0%
Mississippi	78	11	7	5	0.7%	0.4%	0.7%	0.7%
Tennessee	244	52	19	13	2.2%	1.8%	1.6%	1.9%
Regional sub-total	**628**	**116**	**52**	**35**	**5.6%**	**4.0%**	**4.5%**	**5.3%**

Potential annual demand for total grid-connected PV in 2010, by state and installed system price scenario (2 of 2).

Grid Connected Total:Demand in 2010								
State	Annual demand (MWp) in 2010				% share of annual demand in 2010			
System price ($/Wpdc) >>	$ 1.00-1.25	$ 2.00- $ 2.50	$ 3.00-3.75	$ 4.25-5.30	$ 1.00-1.25	$ 2.00- $ 2.50	$ 3.00-3.75	$ 4.25-5.30
South - South Atlantic								
Delaware	36	8	2	2	0.3%	0.3%	0.2%	0.3%
Florida	837	170	50	36	7.4%	5.9%	4.3%	5.4%
Georgia	359	104	31	18	3.2%	3.6%	2.7%	2.6%
Maryland	144	20	11	7	1.3%	0.7%	0.9%	1.1%
North Carolina	430	97	27	21	3.8%	3.4%	2.4%	3.1%
South Carolina	186	35	12	9	1.6%	1.2%	1.1%	1.3%
Virginia	167	22	14	9	1.5%	0.7%	1.2%	1.4%
Washington, DC	23	5	2	1	0.2%	0.2%	0.1%	0.2%
West Virginia	23	5	4	2	0.2%	0.2%	0.3%	0.4%
Regional sub-total	**2,205**	**466**	**152**	**105**	**19.5%**	**16.1%**	**13.3%**	**15.8%**
South - West South Central								
Arkansas	78	10	6	4	0.7%	0.3%	0.5%	0.6%
Louisiana	222	41	13	10	2.0%	1.4%	1.2%	1.4%
Oklahoma	68	11	7	5	0.6%	0.4%	0.6%	0.7%
Texas	727	79	50	33	6.4%	2.7%	4.3%	5.0%
Regional sub-total	**1,096**	**140**	**76**	**51**	**9.7%**	**4.8%**	**6.7%**	**7.7%**
West - Mountain								
Arizona	312	86	19	13	2.8%	3.0%	1.6%	2.0%
Colorado	148	18	12	8	1.3%	0.6%	1.0%	1.2%
Idaho	52	10	5	3	0.5%	0.3%	0.4%	0.5%
Montana	44	7	4	3	0.4%	0.2%	0.3%	0.4%
Nevada	136	32	9	5	1.2%	1.1%	0.8%	0.8%
New Mexico	129	35	11	6	1.1%	1.2%	1.0%	0.9%
Utah	45	6	4	3	0.4%	0.2%	0.3%	0.4%
Wyoming	13	2	1	1	0.1%	0.1%	0.1%	0.1%
Regional sub-total	**878**	**197**	**65**	**42**	**7.8%**	**6.8%**	**5.7%**	**6.4%**
West - Pacific								
Alaska	11	2	1	1	0.1%	0.1%	0.1%	0.1%
California - 1	1,294	504	211	94	11.5%	17.4%	18.4%	14.1%
California - 2	89	23	10	4	0.8%	0.8%	0.9%	0.6%
California - 3	1,369	630	267	147	12.1%	21.7%	23.3%	22.1%
Hawaii	97	40	17	6	0.9%	1.4%	1.4%	1.0%
Oregon	65	11	7	5	0.6%	0.4%	0.7%	0.8%
Washington	46	12	7	4	0.4%	0.4%	0.6%	0.6%
Regional sub-total	**2,970**	**1,223**	**520**	**262**	**26.3%**	**42.1%**	**45.3%**	**39.3%**
U. S. Total	**11,285**	**2,901**	**1,148**	**666**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Potential annual demand for total grid-connected PV in 2015, based on the assumptions discussed in the report is estimated at 4.0 GWp.

S-Curve to Calculate Potential Demand in 2015



Potential Demand in 2015

Residential

System size = 2.5 kW
Technical Market (MWp) = 385,790

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$1.25	7,407	1.92%	9.3
$2.50	1,328	0.34%	3.3
$3.75	410	0.11%	1.5
$5.30	222	0.06%	1.2

Commercial

Commercial - Small/Medium and Large Total
System size = 15 kWp, 100 kWp
Technical Market (MW) = 326,074

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$ 1.00 - 1.10	8,234	2.53%	8.9
$ 2.00 - 2.20	2,692	0.83%	5.9
$ 3.00 - 3.30	1,181	0.36%	3.9
$ 4.25 - 4.65	701	0.22%	3.2

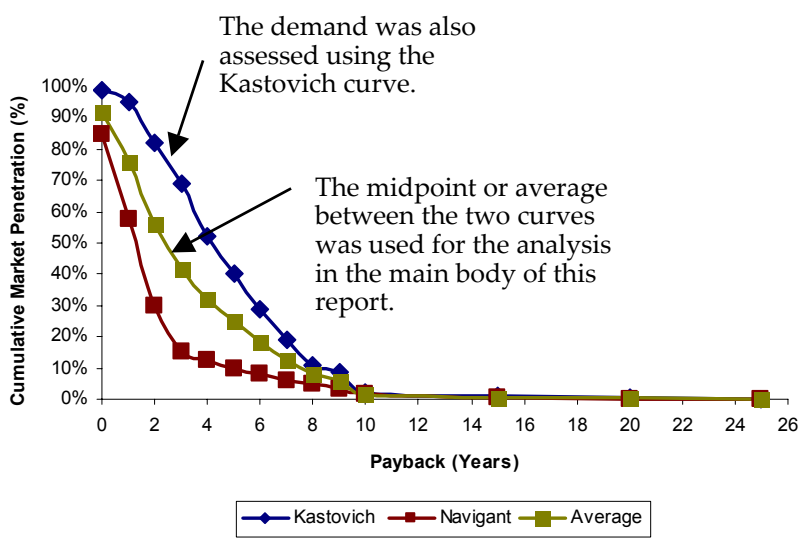
Grid Connected - Total

Technical Market (MW) = 711,864

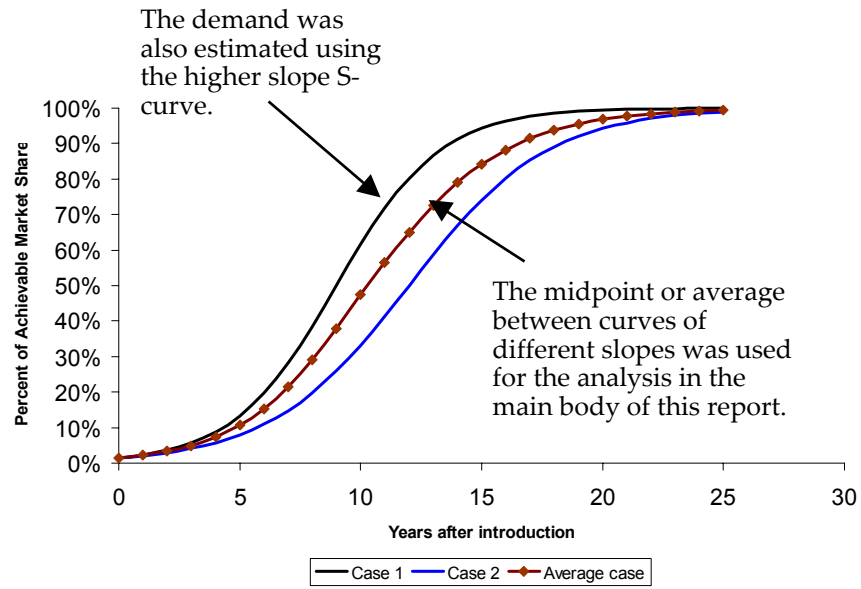
System Price ($/Wpdc)	MWp	% mkt share	$ billion
$ 1.00 - 1.25	15,641	2.20%	18.2
$ 2.00 - 2.50	4,020	0.56%	9.2
$ 3.00 - 3.75	1,591	0.22%	5.4
$ 4.25 - 5.30	923	0.13%	4.4

As an additional analysis, the Kastovich penetration curve and higher slope S-curves were used to estimate demand.

Payback vs. Cumulative Market Penetration Curves[1]



Typical S-Curve



- **NCI believes that using the higher penetration curve and higher slope S-curve is aggressive, given the market development efforts needed to grow and realize the PV market (e.g., additional manufacturing and infrastructure development).**
- **However, the additional analysis was conducted at the request of The Energy Foundation. It does not represent the view of NCI.**

1) Kastovich, J.C., Lawrence, R.R., Hoffman, R.R., and Pavlak, C., 1982, "Advanced Electric Heat Pump Market and Business Analysis.". The curves apply simple payback as the criteria, and were developed for the residential market. The Navigant curve: Proprietary data belonging to Navigant Consulting. Developed by the Navigant team while at Arthur D. Little, based on HVAC penetration experience for the Building Equipment Division, Office of Building Technologies, U.S. Department of Energy (DoE) in 1995. The Navigant curve is used by the DoE in its evaluation of energy efficiency and distributed energy technologies, which was confirmed in an interview with Steve Wade in January 2004.

NCI believes that using the higher penetration curve and higher slope S-curve is aggressive, but conducted the analysis at the request of EF.

Potential Annual Demand in 2010

Residential

System size = 2.5 kW
Technical Market (MWp) = 385,790

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$1.25	5,344	1.39%	6.7
$2.50	958	0.25%	2.4
$3.75	296	0.08%	1.1
$5.30	160	0.04%	0.8

Commercial

Commercial - Small/Medium and Large Total
System size = 15 kWp, 100 kWp
Technical Market (MW) = 326,074

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$ 1.00 - 1.10	5,941	1.82%	6.5
$ 2.00 - 2.20	1,942	0.60%	4.2
$ 3.00 - 3.30	852	0.26%	2.8
$ 4.25 - 4.65	506	0.16%	2.3

Grid Connected - Total

Technical Market (MW) = 711,864

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$ 1.00 - 1.25	11,285	1.59%	13.1
$ 2.00 - 2.50	2,901	0.41%	6.6
$ 3.00 - 3.75	1,148	0.16%	3.9
$ 4.25 - 5.30	666	0.09%	3.2

Potential Annual Demand in 2010 – Higher Curves

Residential

System size = 2.5 kW
Technical Market (MWp) = 385,790

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$1.25	11,350	2.94%	14.2
$2.50	1,796	0.47%	4.5
$3.75	515	0.13%	1.9
$5.30	284	0.07%	1.5

Commercial

Commercial - Small/Medium and Large Total
System size = 15 kWp, 100 kWp
Technical Market (MW) = 326,074

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$ 1.00 - 1.10	12,840	3.94%	8.8
$ 2.00 - 2.20	3,862	1.18%	5.8
$ 3.00 - 3.30	1,574	0.48%	3.8
$ 4.25 - 4.65	892	0.27%	3.2

Grid Connected - Total

Technical Market (MW) = 711,864

System Price ($/Wpdc)	MWp	% mkt share	$ billion
$ 1.00 - 1.25	24,190	3.40%	23.0
$ 2.00 - 2.50	5,657	0.79%	10.3
$ 3.00 - 3.75	2,090	0.29%	5.7
$ 4.25 - 5.30	1,176	0.17%	4.7

The demand estimated using the alternative curves is almost twice.

Contact Information

Lisa Frantzis | Director
77 South Bedford Street
Burlington, MA 01803
lfrantzis@navigantconsulting.com
781-564-9614 direct

Dr. Tom E. Hoff | Principal
Clean Power Research
10 Glen Court
Napa, CA 94558
tomhoff@clean-power.com
707-224-9992 direct

RightCycle
Relentless pursuit of a sustainable future

RightCycle Responses to Questions on 33% RPS Implementation Analysis Preliminary Results report

1. Has this study produced information that is useful for planning or policymaking purposes? Would a more detailed study provide additional value for either planning or policy purposes, or both?

The study should be expanded to compare the cost of electricity for each scenario over an extended period of time. The cost of generation for the renewable energy sources should remain relatively flat over time. This is not true for conventional natural gas-fired resources. The Commission report assumes an increase of 16.7 percent in the cost of electricity from the "all natural gas" reference case from 2008-2020. If the rate of increase is assumed to continue through 2040 or 2050, the cumulative result is likely to be that any of the 33 percent by 2020 alternatives would be more economically beneficial over time than the "all natural gas" scenario.

2. Do you agree with the study's general conclusions that (a) the 2020 timeline is aggressive, (b) the state's process reforms are likely to speed the timeline, (c) the state faces risks that are outside of its control that can affect the state's ability to achieve 33% on a given timeline, (d) the rate impacts of 33% relative to 20% are in the 3-10% range, and (e) there are tradeoffs among the different strategies for achieving 33%?

The study's general conclusions appear to be incorrect because they are based on: 1) too limited an economic analysis (single 2020 year only), 2) excessively high PV capital cost and fixed O&M cost assumptions, and 3) too high a renewable energy gap to meet 33 percent by 2020. Issue 1 is addressed in the previous comment. Issue 2 should be addressed by adding a second high DG case that assumes use of fixed thin-film PV with a 2009 cost of $3.70/We instead of single-axis tracking polycrystalline silicon PV at a cost of $7/We. Issue 3 can be addressed by using the 2020 net short renewable energy requirement identified by the CEC of 45,481 GWh instead of the 74,650 GWh used by the Commission in the study.[1]

RETI explained the genesis of the $3.70/W-e thin-film PV capital cost value as:[2]

> An "alternate scenario" was proposed in the report (Section 3.8) to test lower future solar costs. Black & Veatch will run this scenario for thin film photovoltaic systems with a capital cost of $2,700/kWe to $3,500/kWe. This is based on module costs of $1,500/kWe to $1,700/kWe and "balance of system" costs of $1,200/kWe to $1,800/kWe. These module costs are based on First Solar's 2010 target production cost of $0.90/watt (dc). Balance of system includes inverters, installation, mounting systems and site costs."

[1] California Energy Commission Staff Report, *Impact of Assembly Bill 32 Scoping Plan Electricity Resource Goals on New Natural Gas-Fired Generation*, CEC-200-2009-011, June 2009, Table 5 (line 12), p. 14.
[2] RETI Phase 1A report, May 2008, Appendix B, p. 5-5.

First Solar states its average panel production cost is the second quarter of 2009 was $0.87/watt (dc),[3] slightly less then the $0.90/watt (dc) price basis used by Black & Veatch to establish a $2,700/kWe to $3,500/kWe price range for thin-film PV in the RETI process. Therefore use of a $3.70/We ($3,700/kWe) capital cost appears conservative for thin-film PV in 2009, and a probable overestimate of the average cost of distributed PV installed in the 2010-2020 timeframe. The CEC stated a fixed O&M cost for single-axis tracking PV of $21.31/kW-yr in its December 2007 comparative analysis of electric generation technologies.[4] E3 states a fixed O&M cost for single-axis tracking PV of $53.70/kW-yr.[5] The E3 fixed O&M cost for PV is two-and-a-half times higher than the CEC value. E3 provides no supporting documentation for the high fixed O&M cost. The unsupported fixed O&M cost used by E3 adds $15/MWh to the cost of PV generation when compared to the fixed O&M cost assumed by the CEC.[6] The study should use the CEC fixed O&M assumption for single-axis PV. The fixed O&M cost assumption for non-tracking thin-film PV arrays should be lower than the assumption for tracking arrays.

3. The goal of the resource ranking and selection process was to produce "plausible", but not necessarily "optimal" portfolios for achieving a 33% RPS by 2020. Under the assumption that 33% itself is plausible, do you believe the resource mixes that are modeled are "plausible"? If not, what would a plausible resource mix be? How would you alter the modeling process to produce plausible portfolios?

One plausible portfolio that is not evaluated is a portfolio that relies on distributed PV alone to meet the net short need. The study relies heavily on RETI reports. RETI conducted a sensitivity analysis meeting the 33 percent renewables target primarily with distributed PV and identified 27,500 MW of distributed PV potential that could produce 58,775 GWh per year.[7] The RETI report states that the $3,700/kWe PV price assumption makes 45,000 GWh of distributed renewable resources cost-competitive, the large majority of which are distributed PV resources.[8] For the sake of analysis all of this distributed resource should be assumed to be PV. This 45,000 GWh cost-competitive distributed PV resource is equivalent in size to the net short renewable energy gap identified by the CEC in June 2009 of 45,481 GWh.

Navigant under contract to the CEC estimates that California substations on-line in 2020 could accept up to 21,700 MW of PV input in 2008 with no substantive change to current utility interconnection procedures, and up to 41,500 MW in 2020.[9] 21,700 MW of PV would produce

[3] GreenTechMedia, First Solar fears competitive from silicon panel makers, July 30, 2009.
[4] CEC Final Staff Report, Comparative Costs of California Central Station Electricity Generation Technologies, December 2007, Table 3, p. 10.
[5] E3, Inputs and Assumptions to 33% Renewables Portfolio Standard Implementation Analysis, prepared for California Public Utilities Commission, July 2009, p. 12.
[6] Assume a 1,000 kW (1 MW) PV array. The difference in fixed O&M cost between E3 and the CEC is $53.70/kW-yr - $21.31/kW-yr = $32.39/kW-yr. This equals and annual net additional expense of $32.39/kW-yr x 1,000 kW = $32,390/yr. RETI assumes that a 1 MW PV array generates 2,137 MWh per year (see footnote 10 below). Therefore the high fixed O&M cost assumed by E3 burdens PV with an additional $32,390/2,137 MWh = $15/MWh of unsupported O&M expenses.
[7] RETI, Phase 1B draft report, November 4, 2008, p. 6-23.
[8] Ibid, p. 5-15 and p. 5-16.
[9] Navigant, *Distributed Renewable Energy Assessment – Final Report*, prepared for CEC Public Interest Energy Research, August 11, 2009, pp. 21-30.

approximately 46,400 GWh per year of electricity.[10] Therefore California currently has the interconnection capacity available to accommodate sufficient distributed PV resources to meet a net short gap of 45,481 GWh.

4. The 33% RPS Reference Case relies heavily on resources that have been selected through IOU solicitations and are therefore represented in the CPUC ED RPS project database. Do you agree with the methodology for treating CPUC Database resources (i.e., treating their costs as "sunk" for ranking purposes)? If not, what would be an alternative method of incorporating those projects?

This approach seems reasonable.

5. After exhausting the CPUC ED Database projects, the model fills the remaining need using RETI pre-ID or proxy projects. Do you agree that RETI is a reasonable source of additional project availability and performance data?

Yes, taking into consideration Response 3 above.

6. In addition, the model relies on out-of-state resource availability and performance data from E3's GHG Calculator (the original data came from NREL and EIA). Do you agree that out-of-state projects are characterized accurately and are a reasonable source of energy to meet California's RPS needs?

Out of state resourcing is not reasonable for meeting California's RPS needs. Federal tax credits provide huge subsidies toward the cost of deploying renewable energy. The economic activity is badly needed in California in order to create jobs and drive tax revenue. Studies from NREL and others have definitively concluded that jobs and economic benefits accrue to the regions where renewable energy is deployed. Out of state resourcing steals these immense economic benefits from the State of California and its ratepayers/citizens.

7. The final source of project data is the original estimates of DG potential developed by E3 and Black & Veatch. Do you agree that these estimates are plausible and a reasonable source of information for a study of this nature?

Use of the Black & Veatch distributed PV potential estimates is reasonable. E3 appears to restrict the quantity of distributed PV that could be utilized to meet the 33% RPS target to 15,000 MW without sufficient supporting justification. Table 17 of the study states a combined commercial and residential rooftop PV potential for California of 6,034 MW. No supporting references are provided. Navigant estimated a commercial and residential rooftop PV potential for California of 60,929 MW in August 2009, ten times the technical potential identified by E3 in the study.[11] The Navigant assessment was funded by the CEC. Commercial parking lots are a major focus of PV development in California, and likely have a significantly greater PV potential than commercial

[10] RETI states that 27,500 MW of PV would produce 58,775 GWh per year of electricity (2,137 MWh per year per MW of PV). Therefore 21,700 MW of PV would produce: (21,700 MW/27,500 MW) x 58,775 GWh per year = 46,379 GWh per year.

[11] Navigant, *Distributed Renewable Energy Assessment – Final Report*, prepared for CEC Public Interest Energy Research, August 11, 2009, p. 10.

rooftops. E3 makes no estimate of the PV potential of existing commercial parking lots in the study.

E3 also assesses a transmission penalty cost to distributed PV that interconnects to remote substations, stating that:[12]

> "In remote areas, E3 assumed that ground mounted two-axis tracking PV installations could be developed above the 30% cap at the local substation level, but assigned a cost penalty of $52/Megawatt-Hour (MWh) to reflect the transmission upgrades that would be associated with integrating this much capacity."

No additional supporting information is provided by E3 to justify this high transmission cost penalty for remote distributed PV. E3 assumes that the majority of the distributed PV would interconnect to remote substations.[13] This assumption conflicts with comparable remote PV arrays that are already in operation. For example, the Sempra Generation 10 MW PV array in Nevada is a ground-mounted fixed thin-film array, not a two-axis tracking PV array. Sempra has stated that no transmission upgrades were necessary to interconnect this 10 MW PV array. The $52/MWh penalty for distributed PV interconnected to remote substations should be deleted from the high DG scenario.

No substantive information is provided by E3 to support limiting rural substation power inflows from distributed PV to 10 percent of substation capacity while assuming a 30 percent limit for urban/suburban substations.

The study also makes the following erroneous statement regarding PV cost:

> "The cost impact of the High DG Case is significantly higher than the 33% RPS Reference Case, with a 14.6% cost premium compared to the 20% RPS Reference Case, and a 7% cost premium compared to the 33% RPS Reference Case. This is due to the heavy reliance on solar PV resources, which are currently much costlier than wind and central station solar."

This statement is only true if all PV is assumed to be single-axis tracking polycrystalline silicon PV at 2007 prices, which is a ridiculous assumption. This caveat must accompany the above statement, along with a second statement clarifying that use of fixed thin-film PV would result in distributed PV being lower-cost than central station solar.

8. The 33% RPS Reference Case relies very heavily on solar thermal resources, which are largely untested at utility scale. Do you believe it is reasonable to rely on 7200 MW of solar thermal resources coming online by 2020?

No. Solar thermal resources are higher cost than state-of-the-art thin-film PV resources and they generally rely on decades long transmission build-outs. Additionally, the standard design of the solar thermal technology with the longest development history, solar trough, is a major consumer

[12] E3, Inputs and Assumptions to 33% Renewables Portfolio Standard Implementation Analysis, prepared for California Public Utilities Commission, July 2009, p. 5.
[13] See p. 90. Remote DG, 9,000 MW, 19,236 GWh.

of water. If water is not used for cooling the technology is significantly less efficient during peak demand periods. It is unclear where the water will come from to cool 7,200 MW of solar thermal projects. Land use and transmission siting issues are also likely to stall or stop many solar thermal projects. Distributed PV minimizes or avoids these problems with solar thermal technology and solar thermal siting. As a result, the de facto utility compliance strategy is likely to consist of a much higher proportion of distributed PV than currently included in the 33% RPS Reference Case.

9. The High Wind Case relies on substantial quantities of in-state wind resources. However, many of the projects identified are "proxy" projects from the RETI database, rather than projects that have been identified by developers. In addition, solar projects are heavily represented in the CPUC Database. Given the model's preference for wind resources due to cost, why do you think that more wind projects haven't been selected for development through IOU solicitations?

The model is inadequate in that it apparently does not value time-of-production. Solar resources are reliable peak demand resources, wind is not. Solar resources inherently produce more valuable power on an hour-to-hour basis than wind resources in California. Additionally, high quality solar resources are available in far more locations throughout California and Wholesale Distributed Generation (WDG) solar is not dependent on the massive and decades-long transmission build-outs that hamper wind.

10. The High Out-of-State case relies on substantial quantities of wind from Wyoming and geothermal from northern Nevada. Do you think it is plausible to rely on these resources coming online by 2020, including transmission to California? Are there other challenges with out-of-state resources, such as limited availability of firming and shaping capacity?

There are many significant issues to relying on out of state resourcing: stealing the economic benefits from California, decades-long transmission build-outs, and with respect to wind, the fact that wind generally delivers energy when it is needed least.

11. The High DG case relies on 15,000 MW of in-state solar PV resources. Do you believe it is plausible to develop PV resources on this scale by 2020? Are there any operational issues associated with relying on this quantity of PV resources that the study did not consider? Are the PV potential estimates reasonable and plausible?

See Response 3. Spain added approximately 2,600 MW of mostly WDG PV resources in 2008. Spain has a smaller economy than California. Germany, with a solar resource quality about half as good as California's, added approximately 1,500 MW of WDG PV resources in 2008 and is on track for another 2,000 MW of WDG PV in 2009. At either of these demonstrated PV installation rates, California would easily install 15,000 MW of PV resources by 2020.

12. All of the cases assume that new transmission is required to deliver most (but not all) of the RPS resources to load. Do you agree that new transmission is needed in most cases, or are new resources likely to be able to make more use of the existing transmission system, e.g., by displacing existing fossil resources in the hourly dispatch?

A strategy relying on WDG renewables would obviously require no new transmission. Additionally, because of broad availability, solar resources can preferentially located within the

distribution grid and along existing transmission lines. That is generally not true in the case of wind. California has an extensive existing high voltage transmission network, especially in Southern California desert regions. There is no clear reason why any significant amount of new transmission should be needed to meet a 33% RPS target, even if the strategy selected relies heavily on remote utility-scale renewable resources.

13. The geothermal resources around the Salton Sea are already served by excess transmission capacity. Do you believe it would be an improvement to the study methodology to account for the ability of the existing transmission system to accommodate new renewable resources? What would be a good method of doing this?

Renewable resources would always be dispatched first under normal utility dispatch procedures as they have virtually no incremental cost. One methodology would be to use projected economic dispatch order to allocate renewable generator capacity on existing transmission lines. For example on an existing 1,000 MW line, up to 1,000 MW of renewable resources could be interconnected to the line as all of these units would inherently be higher in the economic dispatch order than any natural gas or other fossil units. Long-term contracts between utilities and specific fossil units that would otherwise occupy capacity on these lines would have to be prohibited for this approach to function.

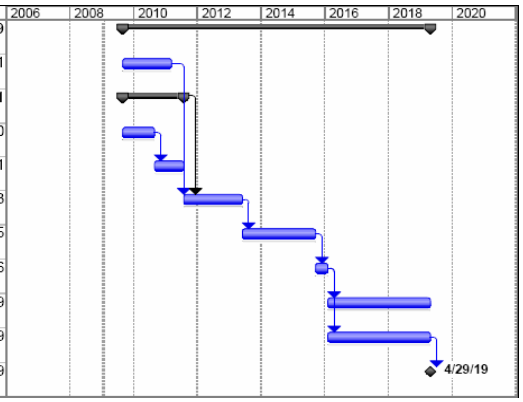
14. Do you believe that a detailed mapping of 33% RPS resources is valuable for transmission and procurement planning? Why or why not?

Absolutely yes. The utilities' largest capital expenditures are for distribution upgrades and these investments need to be focused in order to accommodate WDG renewables that provide the only viable pathway to meeting California's RPS mandates on schedule. If the utilities are not coordinating their annual T&D investments with renewables deployments, then the ratepayers of California will double-pay for the T&D upgrades required to bring renewables online; and this would be equivalent to stealing from ratepayers.

15. Please include any additional comments on the report, including the implementation timelines and assumptions used to build the implementation timelines.

This CPUC chart is very telling that California cannot rely on central station or out of state resourcing: It shows that the fastest possible timeline for a transmission build-out is 10 years; and this assumes no environmental, supply, and/or legal delays:

ID	Task Name	Duration	Start	Finish
1	**Generic Timeline**	**126 mons**	**9/1/09**	**4/29/19**
2	**RFO Process for Generation Resources**	20 mons	9/1/09	3/14/11
3	**Interconnection Queue Process**	**25 mons**	**9/1/09**	**8/1/11**
4	System Impact Studies to Generator Fiancial Commitment	13 mons	9/1/09	8/30/10
5	Develop Transmission Plan for Buildout and Upgrades	12 mons	8/31/10	8/1/11
6	**Prepare PEA/CPCN**	24 mons	8/2/11	6/3/13
7	**CEQA/NEPA Review**	30 mons	6/4/13	9/21/15
8	**CPUC or CEC Decision Process**	5 mons	9/22/15	2/8/16
9	**Transmission Line Final Design & Construction**	42 mons	2/9/16	4/29/19
10	**Generation and Tie Lines to Renewable Resources**	42 mons	2/9/16	4/29/19
11	**Supply Chain Time Requirement**	0 days	4/29/19	4/29/19



CAISO: How its transmission planning process has lost sight of the public's interest

A critical review of the California Transmission Planning and Approval process under the CAISO Oversight: Why Public Policy Goals are in Danger and Consumer Interests in Jeopardy.

Author: Jaleh Firooz, P.E.
April 15, 2010

Funding

This report was funded by Utility Consumers' Action Network, a San Diego-based non-profit consumer advocacy group. While UCAN has funded the report, UCAN did not influence the content of it and did not direct the research method, nor modify any of the content, calculations, findings or recommendations.

About the author

Jaleh Firooz is an expert in the field of energy markets, transmission, and electric regulatory policy. Ms Firooz is the founder of Advanced Energy Solutions, a consulting company in San Diego, California. Ms. Firooz has more than 25 years of experience in the utility and energy industry. She worked more than twenty years for the San Diego Gas and Electric Company in the engineering, operations, transmission and resource planning, procurement, and regulatory affairs groups. Over the course of her consulting career, Ms. Firooz has provided expert testimony and analysis, advised merchant generation and transmission companies doing business in California and throughout the United States. She provides technical and regulatory advice to developers of renewable energy projects, focusing on project economics, siting, permitting, transmission interconnection, and purchase power agreements. She has participated in numerous transmission planning activities in California including the recent Renewable Energy Transmission Initiative (RETI) and California transmission Planning Group (CTPG).

Ms. Firooz holds an M.B.A and B.S. in Electrical Engineering. She is a registered Professional Engineer in the state of California since 1985.

This report is available on the UCAN and Advanced Energy Solutions websites: (www.firoozconsulting.com)

Table of Contents

1.0 Executive Summary..... 7
2.0 Introduction..... 13
2.1 Background..... 13
2.2 California Statute and CAISO Tariff…..... 13
2.2.1 California Public Utilities Code section 345.5 states…..... 13
2.2.2 CAISO Tariff Section 24.1.1..... 14
2.2.3 CAISO Large Generator Interconnection Process (LGIP) 14
2.3 Transmission Approval and CEQA/NEPA Processes..... 14
2.4 Who is in Charge of Transmission Planning in California? 16
2.5 Implementation of Recommendations..... 17
3.0 Findings
3.1 Finding 1 – The IOUs', the CAISO's, and renewable generation developers' existing incentives favor transmission infrastructure additions over alternatives that are not capital-intensive..……..... 18
3.2 Finding 2 - The rate of transmission expansion over the past decade has significantly outpaced the growth in energy demand. Transmission is not in short supply. 18
3.3 Finding 3 - Existing regulatory approval processes do not provide adequate consumer protection. 19
3.4 Finding 4 - Transmission expansion projects associated with renewable development are being approved without any economic comparison to alternatives..... 20
3.5 Finding 5 - The CAISO's generator interconnection process is critically flawed and is disrupting progress towards renewable goals. 21
3.6 Finding 6 – Existing reliability criteria are overly rigid and existing economic evaluation practices too unprincipled. They do not provide a sound basis for identifying and comparing proposed projects and feasible alternatives..... 22
4.0 Recommendations
4.1 Recommendation 1 – Tie IOU Profits to Grid Utilization..... 23
4.2 Recommendation 2 - Modify Transmission Planning Study Methodology and Reliability Evaluation Criteria. 25
4.2.1 Require a Listing of Alternatives..... 25
4.2.2 Conduct Annual Deliverability Study..... 26
4.2.3 Modify the CAISO's reliability criteria to match NERC and WECC Reliability Criteria..... 27
4.2.4 Move to a probability- based reliability analysis approach..... 28
4.2.5 Adopt a Transparent Process for Developing Starting Point and Input Assumptions used in the Reliability and Economic Study Models …….. 29
4.3 Recommendation 3 – Modify the CAISO Generator Interconnection Process 29
4.3.1 Study Methodology Modifications..... 29
4.3.2 Eliminate the distinction between "Full Capacity" and "Energy Only"……. 30

4.4 Recommendation 4 - Regulatory Modifications..... 31
5.0 Discussion
5.1 What are the IOUs', Municipal Utilities', the CAISO, and Generation Developers' Incentives in Transmission Expansion? 32
5.1.1 Investor Owned Utilities..... 32
5.1.2 Municipal Utilities..... 32
5.1.3 Generation Developers..... 33
5.1.4 California Independent System Operator..... 34
5.2 Where Does the Perception of a Transmission Shortage Come from and Is It True? 36
5.2.1 Perception..... 36
5.2.2 Does the Data Support the Perception of a Transmission Shortage? ... 36
5.2.3 What Is Next? 39
5.2.4 Why Should Anyone Care? 42
5.3 Does Existing Regulatory Oversight of Proposed Transmission Protect Consumers? 43
5.3.1 Did the CAISO Perform Due Diligence in Approving the Tehachapi Segments 2.11 Project and in Evaluating the Colorado River-Devers-Valley #2 Project? 44
5.3.2 What about CPUC Oversight of Proposed Transmission Projects? ..... 46.
5.4 Renewable Generator Interconnection: Can Renewable Resource Development Move Forward Without Major Network Upgrades?..... 52
5.4.1 Delivery Network Upgrade Study Process..... 53
5.4.1.a Are the Delivery Network Upgrade Options Appropriate? .. 53
5.4.1.b Are the Interconnection Study Assumptions for the "Full Capacity" Option Appropriate? 55
5.4.2 Absent Major Network Upgrades, Will Existing Grid Uses Preclude the Development of New Renewable Resources? 56
5.4.3 How Do Proposed Changes to the Transmission Planning Process Affect Renewable Transmission Projects? 58
5.5 Are the Modeling Assumptions Used to Determine Grid Needs, Skewed Toward Transmission Expansion? 59
5.5.1 How Is the Capability of the Existing Transmission System Taken into Account in Studies Aimed at Developing Transmission Plans for New Renewable Generation?..... 59
5.5.2 Do Existing Commitments Consume All Existing Transmission Capacity?..... 60
5.5.3 How Are the Generation Dispatch Patterns Selected? 62
5.6. Are Existing Reliability Criteria used in California Unreasonably Rigid? 63
5.6.1 What is "Reliability" and How Is It Measured? 63
5.6.2 How Probable Are Identified Reliability Criteria Violations? 64

List of Appendix (Pages 66-90)

APPENDIX A -
RETI PHASE 2A FINAL REPORT (Posted: September 23, 2009) Proposed Lines
APPENDIX B –
CAISO 2020 RENEWABLE TRANSMISSION CONCEPTUAL PLAN BASED ON INPUTS FROM THE RETI PROCESS (9/15/2009) STUDY RESULTS- Proposed Lines
APPENDIX C -
CTPG FINAL PHASE 1 STUDY REPORT (February 17, 2010) - Proposed Lines
APPENDIX D -
CALIFORNIA IOUs INDIVIDUAL and TOTAL TRANSMISSION RATE BASE
APPENDIX E -
PARTIAL LIST of CALIFORNIA PROPOSED INTERTIES
APPENDIX F -
MAPS of TEHACHAPI and SUNRISE TRANSMISSION LINES

Preface

The objective of this report is to improve the transmission planning and approval processes in California. My peers and I have identified a number of significant problems and we recommend solutions with the hope that it sparks a dialogue on how to get the best value from the state's existing transmission assets and how to maximize the effectiveness of capital available for future investment decisions. The benefits from a reformed transmission planning process will be notable. Renewable developers can avoid the financing and timing challenges associated with poorly conceived transmission upgrades. Consumers will be protected from the billions of dollars in wasteful spending that occur when alternatives are ignored or inadequately evaluated. Transmission owners will be able to focus their resources on transmission projects which are demonstrated to be superior to other alternatives, reducing the level of stakeholder resistance, building consumer confidence in utility planning, and speeding up the regulatory permitting process for new transmission.

The paper is not intended to blame individuals, organizations, or companies for their actions but to point out problems with the existing process. The organizations involved in planning and approving transmission largely act in accordance with the incentives they are provided. As described below, changing those incentives will be key to improving the way transmission is developed in California.

1.0 Executive Summary

This paper examines the California Independent System Operator's (CAISO's) transmission planning and approval processes, its incentives as they relate to transmission infrastructure additions and cost recovery mechanisms used to ensure transmission developers are made whole for their investments.[1] The paper examines the transmission need determinations and evaluation processes used by the California Public Utilities Commission (CPUC) in recent decisions to approve several major transmission expansion projects. It explores whether the CAISO's and CPUC's actions with regard to proposed transmission projects are in the public interest, whether their activities are promoting the development of renewable power in California, and whether these regulatory authorities are using public dollars in a thoughtful manner.

This paper investigates:

- The existing transmission incentives set by FERC, their ramifications, and the extent to which regulatory oversight is effective in protecting consumer interests by counter-balancing the Investor Owned Utilities' (IOUs') strong incentive to build new transmission.
- Whether reliability criteria and starting point assumptions used to identify reliability criteria violations and associated mitigation measures, including new transmission infrastructure, are reasonable.
- Whether feasible alternatives to proposed transmission infrastructure additions are being considered, and if so, whether regulators are evaluating these alternatives from an economic perspective and basing their decisions to approve or deny proposed transmission infrastructure additions on those economic evaluations.
- The upcoming reforms in transmission approval processes to determine if they are going to improve or worsen existing deficiencies.

The paper considers existing incentives to build transmission and finds that because IOU shareholder profits increase in proportion to the amount of transmission investment, the IOUs have been unduly aggressive in proposing and building new transmission. The paper finds that existing CAISO and FERC regulatory oversight lacks a balancing component to contain the IOUs' zealous transmission-building efforts. In particular, the CAISO has failed to establish that most proposed transmission projects are economically preferable to other feasible alternatives; has, at times, failed to challenge

[1] The CAISO is jurisdictional to the Federal Energy Regulatory Commission (FERC).

the use of questionable study assumptions;[2] and ignores potentially economic non-infrastructure alternatives when evaluating mitigation strategies for identified reliability criteria violations.[3]

Ironically, the CAISO's activities tend to undermine one of its claimed objectives: to promote renewable energy development. Its planning process actually bogs down renewable generation interconnections. CAISO use of overly conservative study assumptions (in some cases, with probabilities of occurrence as low as 1 in a million[4]) to identify reliability criteria violations and transmission projects with costs in the billons of dollars to mitigate those violations, without any economic consideration of feasible alternatives is one of the causes of delay in renewable development.. The financing requirement for these transmission projects creates a formidable barrier to the interconnection of new renewable resources. It causes delays or the abandonment of otherwise viable renewable generation projects.

For example, recent CAISO interconnection studies determined that the Delivery Network Upgrades necessary to ensure full deliverability of new generating capacity in one generation cluster study area would cost almost $1.5 billion.[5] Under existing CAISO generator interconnection rules these costs must be shared among the relatively few projects that chose the "Full Capacity" option in their interconnection requests. This caused some of the "Full Capacity" developers to pull out their requests making it impossible for the remaining developers to raise the funds for the upgrade.

The failure to consider whether feasible alternatives may be more economical than a proposed transmission project could result in the inefficient use of capital and time. Capital and time that could be used to build the substations and radial lines necessary to physically connect new renewable generating facilities to the existing transmission network, is being diverted to costly network upgrades that provide unknown economic benefits (since there is no economic comparison of the network upgrades against feasible alternatives). This capital could also be used to fund incentive programs that offer promise for meeting renewable goals faster and at lower overall costs for

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[2] Examples of conservative study assumptions: RETI ignores the ability of the existing system to accommodate flows of new renewable generation and fails to consider the impact on power flows of backing down existing fossil-fired generation; CAISO assumption that the capacity on the interties with neighboring states is and will remain nearly fully utilized; CTPG modeling assumptions that the path between the southern and northern California will be fully utilized before any new renewable generation is added.

[3] Whether granting the CPUC authority to oversee the CAISO would be possible under the Federal Power Act, and whether such authority would translate into better transmission planning and approval decisions, is an interesting question but well outside the scope of this paper.

[4] See sections 5.5 and 5.6 for a description of the assumptions.

[5] Electricity Journal, December 2009, Vol. 22, Issue 10, "Getting it right on the Grid," article by Nick Puga and Jonathan Lesser.

consumers (e.g., subsidies for distribution-level renewable generation or enhanced energy efficiency programs that lower the amount of renewable resources that need to be added in order to meet established renewable targets). Finally, overly expansive proposals to build new network transmission that may not be cost-effective relative to other alternatives invites resistance from environmental groups concerned with the impact of transmission expansion on the environment.

The existing wide-spread perception of a transmission shortage[6] has resulted in several recent transmission building initiatives.[7] These initiatives are predicated upon the proposition that transmission is in short supply, that the shortage of transmission is the main reason that progress in developing renewable generation is lagging, and that there is an urgent need for more transmission.

To test the proposition that transmission is in short supply, the paper examines whether the amount of money invested in transmission over the past ten years has fallen short of the amount of load growth over this period. The data suggests that the proposition of a transmission shortage is exaggerated.

Table 1. California IOUs' Transmission Investment Growth Versus Load Growth

	Transmission Investment Growth since 1999	Energy Load Growth since 1998
1999 - 2009	84%	9%

Note: Data from FERC Form 1 and from the CEC's 2009 Integrated Energy Policy Report. The average annual increase in the Consumer Price Index (CPI) between 1999 and 2010 is 3%.[8]

While the current transmission planning and approval processes have resulted in the approval of multi-billion dollar transmission expansion projects--which may or may not have been needed given the above deficiencies--the cost of transmission additions

[6] Example: newspaper article By Paul Davidson, USA TODAY, Updated 2/26/2008

[7] RETI, CTPG, WGA WREZ and others (see Section 2.23) are forums to plan transmission primarily to meet renewable energy goals. In California, this goal is reflected in the state's Renewable Portfolio Standard (RPS).

[8] Bureau of Labor statistics. The CPI number is calculated using the average Consumer Price Index for every calendar year. This data represents changes in prices of all goods and services purchased for consumption by urban households.

proposed to be added over the next ten years will dwarf the expenditures for these recently approved projects.

Table 2. The Numbers and Costs of Transmission Lines Proposed by the Recent Transmission Planning Initiatives.		
Study	**Total # of lines segments or projects**	**Total Costs**
RETI[9] Phase 2A	104	$ 15.671 billion[10]
CAISO's 9/15/2009 study	54	$ 11.873 billion
CTPG[11] Phase 1	110	No cost estimate made

To put these numbers in perspective, the three largest California IOUs' combined un-depreciated transmission ratebase is currently about $11.4 billion. Therefore, the proposed lines represented in Table 2 above, if approved and built, would more than double the cost of transmission for consumers. Between 1999 and 2009 the California IOUs' combined transmission ratebase has grown by 84% while during the same period, energy loads have grown by only 9%. Assuming that an additional $11 billion in new transmission rate base is added by year 2020 the increase in transmission ratebase since 1999 would, excluding depreciation, be 261%. In contrast, the projected increase in energy loads between 1999 and year 2020 is about 25%.[12]

Since no attempt was made to look at the cost and benefits of any alternatives to the network transmission lines included in the recent RETI Phase 2A conceptual transmission plan, in the CAISO's September 15, 2009 study, and in CTPG's recent Phase 1 transmission plan, these transmission plans are of questionable value. Some parties may assert that economic comparisons of proposed transmission projects against

[9] See the RETI home page: "The Renewable Energy Transmission Initiative (RETI) is a statewide initiative to help identify the transmission projects needed to accommodate these renewable energy goals,"

[10] The list of individual proposed transmission line segments and their associated costs are shown in Appendix A of this paper and were obtained from the RETI Phase 2A Final Report, September 23, 2009, Appendix H.

[11] The California Transmission Planning Group (CTPG) is being organized to provide a forum for conducting joint transmission planning among its members and to coordinate the individual transmission planning activities of the members. CTPG's purpose is to meet California's transmission needs consistent with FERC Order 890. CTPG is currently comprised of the major California IOUs, the CAISO, the Los Angeles Department of Water Power, the Imperial Irrigation District, the Sacramento Municipal Utility District, the Turlock Irrigation District, the Western Area Power Administration, and the Transmission Agency of Northern California (TANC). TANC represents a number of northern California municipal utilities.

[12] CEC **2009 Integrated Energy Policy Report**.

alternatives is not warranted because transmission capital costs are typically small relative to the generation costs. However, even if that assumption is true it is logical to assume that consumers would not knowingly pay for a new transmission line if it was determined that a lower cost alternative was available.

There are no reasonable assurances that spending billions of dollars to implement these transmission plans would materially improve the state's ability to meet its renewable energy objectives or lower the risk of blackouts. Generally, it is assumed that higher transmission operating margins translate into a lower risk of system failure. However, most wide-spread system failures have been the result of poor maintenance or operator error, and depending on the circumstances, higher transmission margins may not protect against these failures. On April 1, 2010 nearly 300,000 homes and businesses in the San Diego area were intentionally blacked-out for a short period of time, approximately two hours. The CAISO has admitted that this black-out was the result of operator error.

State policymakers would be advised to consider whether California can afford to expend precious capital and time on additions to the existing transmission network that may not be needed or cost effective when alternatives are taken into account. This capital might more productively be used to enhance incentives to develop energy efficiency; distributed and central station renewable resources; and to construct the radial "trunk lines," substations and short transmission line "loop-ins" that would connect renewable generation to the existing grid at comparatively modest cost.

The paper also considers recently proposed changes that are designed to streamline and accelerate transmission approval processes. It finds that existing deficiencies could be magnified by recent CAISO initiatives to change the transmission planning and approval processes and by an ongoing CPUC proceeding (OII.08-03-010/OIR.08-03-009) that could eliminate the CPUC's consideration of economic alternatives to transmission expansion projects that come before the CPUC for approval. These initiatives are poised to exacerbate problems by taking advantage of and expanding existing regulations which allow (even compel) regulatory agencies to approve proposed transmission projects with no economic evaluation against feasible alternatives.

This paper will be of greatest interest to decision makers who have the responsibility for ensuring that the future transmission system will allow public policy goals to be met, and to regulatory entities such as the CAISO, FERC and the CPUC who have the responsibility for protecting consumers against the economic and environmental consequences of waste and inefficiency.

Readers will likely be surprised by the absence of meaningful oversight or spending constraints, disturbed by the processes relied upon by CAISO, and dismayed by

the statutory handcuffs placed on the CPUC. They will be troubled by the extent to which the CAISO has become an adjunct of the state's Investor Owned Utilities (IOUs) rather than a moderating force tempering the IOUs' disposition to build costly network upgrades without demonstrating that such upgrades are actually beneficial for consumers.

The current transmission planning process fails to provide consumers with assurances that all reasonable wires and non-wires alternatives have been identified, fails to evaluate sound economic and/or environmental justifications for new transmission, and diverts resources away from the identifying the minimum set of transmission facilities necessary to physically connect new renewable generation. Not only do these deficiencies inflict direct economic and environmental harm on consumers, they are creating formidable barriers within the CAISO's new generator interconnection process, the process by which renewable generators are allowed to connect to the CAISO-controlled transmission network.

In short, this paper documents the existence of one-sided incentives, arbitrary need determinations, and inadequate regulatory oversight for transmission planning. This combination creates a toxic brew of transmission initiatives that are at odds with the state's energy policy goals. At least one of the three -- and preferably all three --have to be overhauled to assure public policy goals can be achieved

The paper's major findings are summarized after the introduction and are discussed at greater depth following the recommendations.

2.0 Introduction

2.1 Background

The objective of this paper is to investigate whether the existing transmission planning and approval processes in California are meeting the needs of consumers and renewable developers, and to recommend changes where those processes are shown to be deficient. As expected, knowledgeable market participants act in accordance with the incentives provided. Where competitive market mechanisms are unable to discipline participant behavior, effective oversight is necessary to limit the opportunity for abuse. Although both California statute and federally-approved tariffs require the CAISO to determine, through cost/benefit analysis, that proposed transmission projects are in the public interest (see section 2.2 below), one of the basic findings of this paper is that this analysis is not being done. Regulatory entities with authority for approving proposed transmission have failed to insist on comparative economic evaluations of proposed transmission projects against reasonable ranges of feasible alternatives. Absent such comparisons, regulatory authorities have no economic bases for determining whether proposed transmission is in the public interest.

Some familiarity with the current transmission planning and approval processes, and the regulatory entities involved in those processes is necessary, and is provided below.

2.2 California Statute and CAISO Tariff

Both California statute and CAISO tariff provisions listed below require the CAISO to determine, through cost/benefit analysis that proposed transmission projects are in the public interest.

2.2.1 California Public Utilities Code section 345.5 states:

"(a) The Independent System Operator, as a nonprofit, public benefit corporation, shall conduct its operations consistent with applicable state and federal laws and consistent with the interests of the people of the state.

(b) To ensure the reliability of electric service and the health and safety of the public, the Independent System Operator shall manage the transmission grid and related energy markets in a manner that is consistent with all of the following:

(1) Making the most efficient use of available energy resources. For purposes of this section, "available energy resources" include energy, capacity, ancillary services, and demand bid into markets administered by the Independent System Operator…

(2) Reducing, to the extent possible, overall economic cost to the state's consumers…"

2.2.2 CAISO Tariff Section 24.1.1

Section 24.1.1 of the FERC-approved CAISO tariff provides that the CAISO will not approve proposed transmission projects if there is a superior alternative or if the proposed project does not pass a cost-benefit analysis.

2.2.3 CAISO Large Generator Interconnection Process (LGIP) (Appendix Y of CAISO Tariff)

The CAISO's LGIP provides that radial gen-ties (transmission facilities connecting an interconnecting generator to the first point of interconnection with the transmission grid) are to paid for and owned by the interconnecting generator such that the generation developer has an incentive to minimize the scope and cost of this type of upgrade. However, the CAISO tariff contains other provisions that Investor Owned Utilities use to identify costly upgrades. For example, if the CAISO is convinced that an area has a high level of commercial development interest, the CAISO can, under section 24.1.3 of its existing tariff, deem the area locationally constrained such that IOUs are permitted to finance, build and ratebase the costs of a radial "trunk line" that connects the constrained area to the existing grid (the CAISO tariff defines such lines as Location Constrained Resource Interconnection Facilities (LCRIF)).

This trunk line is built ahead of the generation projects, in theory, to facilitate the development of renewable generation in the area. As generation in the area gets built, the transmission provider is reimbursed and there is a corresponding decrease in ratebase and profits. But, the net result is that the IOUs earn profits that they would not otherwise have and consumers pay more in these early years. Further, consumers are fully at risk for the failure of generation to develop as expected.

2.3 Transmission Approval and CEQA/NEPA Processes

The transmission planning and approval process starts with the policy goals of meeting load in a safe, reliable, economical, and environmentally responsible manner. Typically, utilities conduct technical studies of the grid to identify reliability criteria

violations. Two main causes behind reliability criteria violations are: 1) load growth that increases power flows on certain lines, and 2) new generation, including renewable resources that may increase power flows on certain lines. With increased power flows, the outage of one or more grid elements can result in power flows on other grid elements exceeding maximum safe ratings, i.e., a reliability criteria violation. The CAISO is responsible for technical studies of interconnection requests to identify reliability criteria violations that may occur with the addition of the generation. Utilities owning transmission facilities within the CAISO balancing authority area, mainly Investor Owned Utilities, usually conduct the technical studies under the direction of the CAISO. The utilities select measures that mitigate the identified reliability criteria violations and these measures are reviewed with the CAISO, which ultimately must approve or otherwise accept those measures prior to their implementation. .

Depending on the circumstances and the specific reliability criteria violations, these mitigation measures can include new transmission infrastructure, strategically-located generation additions, redispatch of existing fossil-fired generation, contingency-based generation tripping, contingency-based line sectionalizing, controlled load drop (for N-2 contingencies), expanded demand side impacts such as new energy efficiency and load management programs, and increased distributed generation.

Some of these mitigation measures require specific regulatory approvals, others do not. For example, proposed transmission infrastructure can require approvals from the CAISO, the FERC and the CPUC. On the other hand, new operating procedures (such as generation tripping and controlled load drop) must be coordinated with the CAISO, but formal approval from the CAISO, the FERC and the CPUC are not required.

Under existing FERC-approved tariff provisions, the CAISO must grant approval for proposed transmission infrastructure within its balancing authority area in order for the costs of those projects to be included in the CAISO's Transmission Access Charge (TAC) cost recovery mechanism. Transmission additions that are proposed outside of the CAISO's generator interconnection procedures are submitted to CAISO for approval via the CAISO's annual grid assessment process. The current CAISO tariff specifies that proposed transmission projects exceeding $50 million in cost, require formal CAISO board approval. However, transmission additions that are identified through the CAISO's generator interconnection procedures, and that are included in an interconnecting generator's Large Generator Interconnection Agreement (LGIA) (which is signed by CAISO management), are not reviewed by the CAISO Board. For FERC-jurisdictional transmission owners, FERC separately approves the mechanism for determining the level of a proposed transmission project's costs that are recoverable from transmission customers (e.g., rates-of-return, depreciation).

California Public Utilities Code section 1001, the CPUC's General Order ("GO") 131-D, and the CPUC's Rules of Practice and Procedure require jurisdictional utilities to obtain a Certificate of Public Convenience and Necessity (CPCN) from the CPUC in order to construct and operate proposed transmission infrastructure projects. In addition GO 131-D (Section IX.A.1.h) requires an applicant for a CPCN to include in its application a Proponent's Environmental Assessment (PEA), or equivalent information that evaluates the environmental impact of the project in accordance with the provisions of the California Environmental Quality Act (CEQA) and the CPUC's Rules of Practice and Procedure, Rules 17.1 and 17.3. As lead agency for CEQA purposes, the CPUC must issue an Environmental Impact Report (EIR) that compares the environmental impacts of the proposed transmission infrastructure addition against the environmental impacts of other alternatives. CEQA requires that the CPUC take the results of the EIR into account when deciding whether to issue a CPCN.[13]

The National Environmental Policy Act (NEPA) requires utilities to submit similar environmental impact information to federal agencies where the proposed transmission infrastructure projects cross federal lands. Federal agencies must prepare an Environmental Impact Statement (EIS) before deciding whether to grant permission to construct the proposed transmission infrastructure project on federal lands.

Because CEQA deals exclusively with *environmental* impacts, the CPUC's failure to conduct a comparative *economic* evaluation of a proposed transmission project against feasible alternatives does not necessarily compromise the CPUC's environmental review. Accordingly, this paper is not alleging that the CPUC's CEQA review is substandard.[14]

2.4 Who is in Charge of Transmission Planning in California?

Currently there is a flurry of regional transmission planning activity. In response to the Department of Energy's Funding Opportunity Announcement (FOA), the WECC submitted a regional transmission planning proposal and on December 18, 2009 was

[13] A non-CPUC jurisdictional utility, e.g., a municipal utility, can usually act as its own lead agency for CEQA purposes.

[14] However, potentially economic non-infrastructure alternatives to a proposed transmission infrastructure project would normally have far fewer adverse environmental impacts. For example, tripping renewable generation for selected contingencies might have environmental consequences for the duration of the contingency (typically a few hours per year), but these consequences are likely insignificant compared to the environmental impacts of a long transmission line that will be a permanent fixture of the landscape for 60 or more years. Environmental review of a proposed transmission infrastructure project should evaluate the environmental impacts of non-infrastructure alternatives where such alternatives are determined to be feasible.

awarded $14.5 million to expand its regional transmission planning activities. At the same time a number of other regional transmission planning initiatives are underway including those of the California Transmission Planning Group (CTPG), the California Renewable Transmission Initiative (RETI), the Western Governors' Association (WGA) Western Regional Energy Zones (WREZ) initiative, the California Independent System Operator, various sub-regional planning organizations across the WECC, and various governmental agencies including municipal utilities, water districts and federal power marketing agencies. Coordination among all of these transmission planning processes to minimize duplication of effort and to develop regional plans that provide the greatest benefit to the largest number of consumers is needed, yet no single entity has plenary jurisdiction or authority. While acknowledging the importance of coordinating or consolidating the numerous regional transmission planning efforts underway, this paper makes no attempt to define how this might be accomplished.

2.5 Implementation of Recommendations

Many of the findings and recommendations in this paper—such as the development of performance base rate making, the standards to be developed for economic evaluation of alternatives, and others--require formation of a study team or stakeholder group. This team or group would vet issues, take input from stakeholders, and develop implementation details. It is recommended that this team or group be made up of informed individuals representing transmission developers, generation developers, the CAISO, FERC, CPUC, other regulatory agencies, environmental organizations, and consumer groups.

The addition of informed consumer group representation is an important improvement over existing transmission planning processes. The lack of direct representation from consumer groups in planning groups such as RETI and CTPG is one of the main reasons that little attention is being given to identifying and evaluating the efficacy of non-transmission infrastructure alternatives. Direct participation by informed consumer groups would help to establish a more even balance between (i) Investor Owned Utilities and generation developers, and (ii) the CPUC and other stakeholders that support consumer interests. Facilitation of the process by an independent entity is important to limit the undue influence of parties motivated by profits (e.g., the IOUs and generation developers.)[15]

This paper's major findings are summarized below and discussed in greater depth following the recommendations.

[15] The WGA WREZ initiative was facilitated by an independent facilitator.

3.0 Findings

3.1 Finding 1 – The IOUs', the CAISO's, and renewable generation developers' existing incentives favor transmission infrastructure additions over alternatives that are not capital-intensive.

The major transmission expansion participants (IOUs, CAISO, renewable generation developers and, to a lesser degree, municipal utilities) have strong financial and operational reasons to want to build more transmission. The existing transmission planning and regulatory approval processes are a reflection of the IOUs' profit incentives, the CAISO's lack of cost accountability, and renewable generation developers' desire to transfer transmission access risks to consumers. Under FERC's existing cost recovery procedures IOUs profit by maximizing their transmission investment. Therefore, capital projects are preferred over operating solutions and large capital projects are preferred over small capital projects. Once the capital is raised and the line is built, cost recovery (which includes a FERC-authorized profit) for IOU transmission investments is virtually assured.

The CAISO's preference for higher operating margins to reduce the possibility of loss of load is unbalanced by any consequential cost accountability. This lack of cost accountability undermines the objectivity with which the CAISO evaluates and approves proposed transmission projects. Because renewable generation developers' responsibility for grid expansion is limited to financing, not paying for, network upgrades (except for the radial line (gen-tie) that connects the generator to the grid, interconnecting generators are fully reimbursed for the funds advanced to construct the network upgrades), renewable generation developers are also largely unconcerned with transmission project costs and will always support grid expansion which improves the market value of their generation projects (e.g., improved capacity value, lower grid losses, and fewer congestion-related impacts).

3.2 Finding 2 - The rate of transmission expansion over the past decade has significantly outpaced the growth in energy demand. Transmission is not in short supply.

The perception of a transmission shortage, and its negative influence on renewable development, is unsupported by the evidence. As shown earlier, California's

IOUs have been adding transmission ratebase at a pace that far exceeds the underlying growth in consumer energy demand[16].

In the next decade consumers could be required to pay for many new transmission projects, some already approved by regulators and others in the planning pipeline. These future projects have estimated costs in the tens of billions of dollars. As shown earlier, transmission additions identified in California's Renewable Energy Transmission Initiative (RETI) total $15.7 billion[17] (this number accounts only for the upgrades associated with new renewable resources) as compared to about $11.4 billion of transmission currently in the IOUs' combined transmission rate base.[18]

Any claim that transmission expansion has been at a virtual standstill over the last decade is not borne out by the amount of money that is being spent, at least not in California.

3.3 Finding 3- Existing regulatory approval processes do not provide adequate consumer protection.

FERC and CPUC approval processes rely heavily on the CAISO's evaluation of and recommendations for proposed transmission projects. An examination of FERC's recent record shows that FERC is inclined to grant favorable rate recovery terms for proposed transmission projects (e.g., rate-of-return incentives) and rarely second-guesses the inclusion of the associated costs in consumer rates. While FERC did not accept the CAISO's last attempt to include an economic evaluation of Delivery Network Upgrades for lack of details, [19] the FERC seems to believe that such an analysis is nevertheless necessary and taking place.[20]

A review of several recent transmission licensing proceedings at the CPUC reveals that the CPUC uses the CAISO's evaluation of proposed transmission projects as

[16] The transmission ratebases and energy loads for individual IOUs are shown in Appendix D
[17] RETI Phase 2A Final Report, September 23, 2009, Appendix H
[18] Transmission rate base from FERC Form 1. Also, see the transmission rate base table in the Discussion section (section 2.b).
[19] FERC's July 1, 2005 "Order Accepting in Part and Rejecting in Part Order Nos. 2003, 2003-A, and 2003-B Compliance Filings" FERC responded to the CAISO's proposal to subject network upgrades identified in generator interconnection studies to an economic test. The FERC rejected the CAISO's proposed economic test without prejudice on the grounds that the CAISO had not "provided the necessary level of specificity within its tariff." (paragraph 114)
[20] Docket No. EL10-19-000e - ORDER ON PETITION FOR DECLARATORY ORDER issued on January 21, 2010 - "The Projects will be subject to review and approval by the CAISO in its transmission planning process. Pursuant to CAISO Tariff section 24.1.1, the CAISO will not approve the Projects if a superior alternative project is proposed or if the Projects do not pass a cost-benefit analysis. Thus, if the CAISO approves the Projects, they would be paid for by ratepayers because the CAISO had found that they were the most efficient solution proposed."

a primary basis for making "need" determinations. Under the current regulatory approval process, the CAISO's role in evaluating proposed transmission projects has become crucial.

This paper finds that the CAISO's objectivity in conducting these evaluations is highly suspect. The CAISO is conflicted by its own self-interest and a demonstrated preference for an ever-larger transmission operating margin. Although the decision-making process for some projects has been lengthy, and some decisions are still pending, no major transmission expansion project formally brought to the CAISO for approval, has, to date, been denied (see table 3 Section 5.4.1.)

Moreover, a review of the CAISO's role in approval of the most recent major transmission projects (Tehachapi Segments 2-11, Sunrise Powerlink, and the Colorado River-Devers-Valley #2 project) shows that almost all of the CAISO's activities have been designed to promote and support approval of the proposed projects rather than to objectively evaluate the merits of the projects' need relative to feasible alternatives.[21]

3.4 Finding 4. Transmission expansion projects associated with renewable development are being approved without any economic comparison to alternatives.

As it stands today, the FERC-approved CAISO tariff effectively provides that any Delivery Network Upgrade (which represents a significant portion of transmission expansion dollars) included in a Large Generation Interconnection Agreement (LGIA) is deemed approved by the CAISO. There is no formal CAISO Board approval process and questions as to potential alternatives, and the comparative costs and benefits thereof, are never posed and never answered.

This low threshold could be further lowered. The CAISO is proposing to create a new transmission project approval criteria that would allow the CAISO Board to approve transmission projects outside of the generation interconnection process that are "needed" for renewable resources on the sole basis of expected renewable development. This proposal is called the Renewable Energy Transmission Planning Process (RETPP). According to the CAISO's proposal, network transmission additions that are "needed" to "access" renewable resources in an area with sufficient commercial interest could be

[21] There have been instances where the CAISO has attempted an evaluation of proposed projects against viable alternatives (e.g., the initial Palo Verde-Devers #2 project versus a generator redispatch alternative and the Sunrise Powerlink project versus several wires and non-wires alternatives), but the diligence and even-handedness with which the CAISO conducted these analyses is not of the caliber that should be expected of an organization with crucial oversight responsibility.

approved by the CAISO Board with no need for identification or economic analysis of viable alternatives.

For proposed transmission projects that the CPUC determines are "necessary to facilitate achievement of the renewable power goals," section 399.2.5 of the California Public Utilities Code appears to require the CPUC to ignore other sections of the California Public Utilities code that otherwise oblige the CPUC to consider, among other things, the project's "influence on environment" (section 1002), "cost-effective alternatives" (section 1002.3), and "cost analysis comparing the project with any feasible alternatives" (section 1003(d)). There is an ongoing CPUC proceeding (OII 08-03-010/OIR 08-03-009) which is examining the CPUC's current implementation of section 399.2.5. As it stands today, the CPUC implements section 399.2.5 by determining whether proposed transmission projects meet the following test: "that the cost of the line is appropriately balanced against the certainty of the line's contribution to economically rational RPS compliance." The IOUs assert that the CPUC's implementation of section 399.2.5 has fallen short of what the state legislature intended when it passed the bill. In its February 17, 2009 opening comments SDG&E went so far as to argue that "…the Commission should abandon the test altogether because it holds no promise to serve the statutory intent…" (Page 5)

Accordingly, California is being subjected to a transmission project approval regime where a project proponent need only demonstrate that the project mitigates an identified reliability criteria violation, and has some nexus to renewable resources, in order to receive automatic regulatory approvals and move the project into the final environmental permitting stages. In this regime, alternatives, regardless of economic competitiveness, are not considered.

3.5 Finding 5 - The CAISO's generator interconnection process is critically flawed and is disrupting progress towards renewable goals.

Even though most regulatory approval requirements for new transmission associated with the interconnection of renewable generation have been either eliminated or lowered, the process remains painfully slow. Only a small fraction of the generation projects in the CAISO interconnection queue have completed interconnection studies and have signed an interconnection agreement. The problem lies elsewhere. Flaws in the interconnection study process (described below), and overly conservative reliability criteria and study assumptions (described in Finding 6 below), are major contributors to the slow pace of interconnecting renewable generators.

For example, the CAISO's existing interconnection rules require an interconnecting generator to choose either a "Full Capacity" or "Energy Only" status for interconnection study purposes. This all-or-nothing approach to interconnecting renewable generation within the CAISO control area forces the renewable generators early on in the process to make uninformed decisions that they may later regret, that could force smaller developers out of the market altogether, and that can result in the commitment of valuable capital and time to transmission additions that may not be cost effective for consumers.

3.6 Finding 6 – Existing reliability criteria are overly rigid and existing economic evaluation practices too unprincipled. They do not provide a sound basis for identifying and comparing proposed projects and feasible alternatives.

Tremendous leeway exists in the study methodologies that are the basis for identifying reliability criteria violations and determining the transmission expansion projects that will mitigate those reliability criteria violations.

1. Use of stressed load conditions combined with highly conservative input assumptions (such as high imports, assuming existing transmission is unavailable to support the connection of new generation, optimistic renewable resource addition forecasts, conservatively set transmission line ratings) will almost always result in reliability criteria violations when contingencies are applied. The amount consumers are willing to pay to protect against an event with very low probability should depend on the severity (i.e., consequence) of the event, and the costs and benefits of wire alternatives, operating procedures, and/or non-wires alternatives that are available to mitigate the adverse consequences of the event.

2. Economic analysis of proposed projects versus feasible alternatives requires meaningful assessments of the many uncertainties inherent in the input assumptions used to estimate the benefits of the proposed transmission facilities (relative to alternatives). The uncertainties are particularly significant because transmission facilities have economic lives of thirty to sixty years, or even longer. (Recommendations regarding specific economic evaluation methodologies are outside the scope of this paper.)

4.0 Recommendations

This paper's evaluation is premised upon the assumption that California must ensure that only those transmission expansion projects that provide the greatest expected economic benefits and lowest adverse environmental impacts relative to feasible alternatives are pursued. Feasible alternatives may include "no project" alternatives such as operating procedures requiring little or no capital expenditures. Sometimes doing little (e.g., relying on the existing grid by redispatching existing generation[22] or connecting new generation to the existing grid by looping-in adjacent transmission lines), is the right decision.

The most efficient and least cumbersome way of using capital effectively is to align consumers', IOU shareholders' and the CAISO's interests. If such an alignment can be made, then prescriptive regulatory oversight could be minimized. If such an alignment proves infeasible, then other changes will be needed to protect consumers.

A complete plan for aligning consumer and shareholder interests is beyond the scope of this paper. The following framework is offered as a starting point for further consideration of ways in which the IOUs' profit incentive can be harmonized with consumer interests in reasonable transmission rates and reliable electric service.

4.1 Recommendation 1 – Tie IOU Profits to Grid Utilization

Consideration should be given to a performance-based ratemaking mechanism that ties IOU profits to how well their existing transmission assets are used. The incentive mechanism should be designed to avoid interference with continued grid reliability, to make the interconnection of renewable generation faster and less costly, and to balance shareholders' and consumers' interests. Once developed, FERC would be the agency to approve such a ratemaking mechanism although other regulating agencies, such as the CPUC, could initiate its discussion and development.

A variety of transmission ratemaking mechanisms are currently being used. In some cases FERC updates allow profit levels for an IOU's entire transmission ratebase to

[22] Reliance on the existing grid may require use of congestion management protocols. This can be a good thing, allowing new renewable generation with low marginal costs to use existing lines and displacing dirtier fossil-fired generation with higher marginal costs.

be adjusted as often as every year.[23] In other cases, FERC has approved incentive rates for specific transmission ratebase additions.[24] Changes to the mechanism by which IOU profits are determined would need to be structured to honor FERC's decisions rendered to date.

Changing the current mechanism by which IOUs earn profits from transmission ratebase would require careful consideration of the numerous details that are involved. For example, directly measuring the annual average usage rate for an IOU's transmission network would require hourly flow measurement on every network transmission element owned by an IOU. Simpler measures, such as using peak load plus a measure of flow-through may be necessary.

Also, with any new ratemaking mechanism comes the risk of unintended consequences. From the start, some way of identifying and protecting against such consequences needs to be built into the new incentive mechanism. A usage-based profit mechanism can create an incentive to propose transmission projects that add ratebase with minimal effects on average annual line usage levels. For example, an IOU could propose to underground an existing section of line with cables providing similar line utilization to the original overhead line.

For discussion purposes consider an IOU that has $1 billion in existing transmission ratebase resulting in an annual revenue requirement of $100 million per year of which $25 million is shareholder profit, and a network consisting of 100 individual transmission line segments. Assume that these 100 individual transmission line segments are being used, on average, at 25% of their rated capability.

In this simple example, assume the IOU's profits could, on a going forward basis, be set at 10% of the total cost of the transmission for each average percent of line use. The IOU would still be entitled to recover the costs associated with the $1 billion of ratebase (e.g., financing costs, depreciation, taxes, operation and maintenance costs), but revenues above these costs (i.e., profits) would be determined by how well existing grid

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[23] See PG&E TO9 (ER06-1325), TO10 (ER07-1213-000), TO11 (ER08-1318), and TO12 (ER09-1521-000) cases, filed in 2006, 2007, 2008, and 2009 respectively. See also the SCE TO4 (ER08-1343)and TO5 (ER09-1534-000)cases, filed in 2008 and 2009.

[24] Examples: Declaratory orders:

Transbay Cable: ER10-116-000
Atlantic Path 15: ER08-374 and EL08-38-000
Ivanpah: El10-3-011
Citizens: EL10-3-011
Green Energy Express: EL09-74-000
The Nevada Hydro Company - Talega-Escondido/Valley-Serrano: ER06-278-000
Western Grid Development: EL10-19-000

assets are used. If nothing changes in the next year, the utility shareholders would earn profits of 0.25 x 0.1 x $1 billion = $25 million. If, however, there was load growth, generation additions, and/or changes in imports/exports that increased average line use to, say, 26% without adding any network transmission, then shareholder profits would increase to 0.26 x 0.1 x $1 billion = $26 million. If, on the other hand, network transmission were added at a cost of $100 million, average line use could decrease, say to 23%. In this case shareholder profits would be 0.23 x 0.1 x $1.1 billion = $25.3 million. In other words, the IOU's incentive would be to identify and implement an operating procedure that accommodated load growth, generation additions and/or changes in imports/exports, rather than building new grid infrastructure.

Under this mechanism IOUs would have an incentive to add ratebase whenever an infrastructure addition would increase ratebase by enough to offset the resulting decrease in line utilization. In the previous example, if in the second year an infrastructure addition was identified that cost $40 million but only reduced line utilization from 26% to 25.5%, the IOU would be better off making the infrastructure addition rather than relying on an operating procedure. (0.255 x 0.1 x $1.040 billion = $26.5 million.) .

IOUs will argue that a transmission incentive mechanism tied to the level of existing grid usage is impossibly simplistic and that there are many critical details that would need to be thoroughly explored before the concept could be embraced. But all other performance based-rate making mechanisms started the same way. The IOUs along with other stakeholder groups could put together a committee who can develop the necessary details where all different situations and scenarios are examined to assure the proposed mechanism functions properly under all or most reasonable scenarios, and steps developed to deal with unanticipated situations. Some may say that this could provide an incentive for more remote generation than distributed generation, but that problem already exists under the current incentive mechanism.

4.2 Recommendation 2 - Modify Transmission Planning Study Methodology and Reliability Evaluation Criteria.

4.2.1 Require a Listing of Alternatives

With the exception of Reliability Network Upgrades, Interconnection Facilities and gen-ties identified in the CAISO's generator interconnection process, sponsors of network upgrades (e.g., transmission additions) should be required to include in their requests for project approval, a list of the alternatives that were considered by the project sponsor when it decided to pursue the proposed network upgrades. If operating procedures or non-wire alternatives were not considered as alternatives, the project

sponsor should explain the reasons. Further, sponsors of network upgrades should be required to demonstrate that the proposed network upgrade is economically superior to the alternatives considered. These requirements should apply regardless of whether the project sponsor asserts that the proposed network upgrade is being done for "reliability reasons," to accommodate load growth or to facilitate the development of renewable resources. The added requirements described in this recommendation should be added to both the LGIP and the CAISO tariff. These additions would require FERC approval. The CPUC could also enforce these requirements from an environmental perspective by making them part of its CEQA review.

Transmission owners and the CAISO will likely claim that all relevant policy-makers have already determined that new transmission is "needed" in order to meet aggressive renewable goals and that further analysis to determine whether a proposed transmission project is more economical than other alternatives is both unnecessary and time-consuming. But this claim rests upon the unsubstantiated belief that a credible process for determining "need" is in place and is being applied. In fact, in only in one major new transmission expansion proceeding has there been any recent attempt to establish that the proposed transmission project was "needed" relative to the costs and benefits of other alternatives (including "no project" alternatives).[25] It is a fact that major transmission projects are being approved without any evidence that consumers will be better off with the project than with other alternatives that also satisfy renewable and environmental policy objectives.

4.2.2 Conduct Annual Deliverability Study

Conduct an annual analysis that determines the deliverability of all existing generation within the CAISO control area assuming no changes to the transmission system. Identify potential alternatives that would enhance the deliverability of existing generation where full deliverability is not otherwise possible. Compare the estimated costs of these alternatives to the projected value of the increase in Resource Adequacy-qualifying capacity. In some cases it may not make economic sense for all generation to be fully deliverable. This requires CAISO action but should not require FERC approval since the FERC has already accepted the deliverability concept.

[25] Sunrise Powerlink (D.08-12-058) and the original Palo Verde-Deves #2 decision contain an economic analysis of alternatives. However, the CPUC's 2009 approval of a revised project that eliminated the Arizona portion of the original Palo Verde-Devers #2 project contained no economic analysis of alternatives. The CPUC's approvals for Tehachapi segments 1-3 and Tehachapi segments 4-11 (D.07-03-045 and D.09-12-044) also had no economic comparisons to alternatives.

The CAISO and IOUs may argue that renewable developers will not move forward with their projects unless they have certainty, via construction of new network transmission, that the output of their generators is "fully deliverable" and will therefore count towards CAISO load serving entities' Resource Adequacy requirements. But this argument misses several key points. First, not all renewable generation will be sold to CAISO load serving entities and, therefore, will not be subject to the CAISO's existing Resource Adequacy requirements. Second, there is a significant amount of generation within the CAISO's existing generator interconnection queue that has chosen the "Energy Only" option under which no Delivery Network Upgrades are even identified. Third, there are no provisions within the CAISO tariff that guarantee:

(i) that the output of an interconnecting generator funding a Delivery Network Upgrade will *always* be fully deliverable, and

(ii) that the output of an interconnecting generator that does not fund a Delivery Network Upgrade will *never* by fully deliverable, and

Fourth, the argument that renewable developers will not proceed with their projects absent the construction of Delivery Network Upgrades, fails to acknowledge the obvious point that the funding hurdle for some Delivery Network Upgrades can be so huge that even the promise of a full refund within five years will not be sufficient to cause lenders to fund the Delivery Network Upgrade.[26]

Finally, and most importantly, if the cost of a network upgrade to consumers exceeds the economic benefits (relative to alternatives) provided by the network upgrade (including increased Resource Adequacy value), consumers are better off if the network upgrade is not built and other alternatives pursued.

4.2.3 Modify the CAISO's reliability criteria to match NERC and WECC reliability criteria

Modify the CAISO's reliability criteria to match NERC and WECC reliability criteria by changing the CAISO's classification of G-1/N-1 outages from a Category B contingency condition (controlled load drop is not permitted mitigation) to a Category C contingency condition (controlled load drop is permitted mitigation). This simple change

[26] There have been instances where the funds necessary to construct Delivery Network Upgrades included in a Large Generator Interconnection Agreement (LGIA) are advanced by the utility rather than the interconnecting generator (see, for example, the LGIA for Phase 2 of Tessera Solar's Calico (formerly SES 1) project). It is unclear what criterion is used to determine which Delivery Network Upgrades will be funded by utilities and the possibility of discrimination exists. In addition, because Delivery Network Upgrades included in LGIAs require neither formal CAISO Board approval nor cost/benefit analysis, such funding by utilities represents another vehicle by which the Investor Owned Utilities can obtain CAISO approval of new transmission without any consideration of potentially economic alternatives.

could save consumers millions of dollars in avoided Reliability Must Run (RMR) costs with no measurable degradation of grid reliability. Utilities can use controlled load drop to mitigate Category C contingencies which means generators within a local pocket would not be required to operate in order to mitigate reliability criteria violations associated with the G-1/N-1 outage condition. If these generators are not required to operate, they will not have local market power and there will be no need to protect consumers through the use of costly RMR contracts.

As a general matter, it does not make sense for California to have more stringent reliability criteria than the rest of WECC. This increases costs and puts load serving entities within the CAISO balancing authority at competitive disadvantage to other balancing authorities, both inside and outside of California. If there are special circumstances where more stringent reliability criteria may be required, those need to be brought up on an exceptional basis and justified rather than being the rule. Changing the CAISO's existing reliability criteria to match that of NERC/WECC would only require action by the CAISO. Approvals from WECC, NERC or FERC do not appear to be necessary.

It may be argued that this recommendation would lower reliability in California. But that is not true at any reasonably measurable level. The CAISO would still meet all applicable NERC and WECC reliability requirements and would be on par with the reliability standards of all other balancing authority areas.

Where a project sponsor or regulatory authority believes existing NERC or WECC reliability criteria are not adequate, or that the assumptions and/or methodology for implementing those criteria are not sufficiently conservative to address the contingency event of concern, the project sponsor or regulatory authority should be required to:

1. Assess the probabilities associated with the contingency based on ten year's of relevant historical outage data.
2. Identify the consequences of the contingency event (e.g., amount and duration of uncontrolled load loss, economic impacts of such load loss, public safety concerns).
3. Provide a justification for applying more conservative reliability criteria than required by WECC and NERC.

4.2.4 Move to a Probability-Based Reliability Analysis Approach

As described later in this paper, move to a probability-based reliability analysis approach and away from the current deterministic approach for evaluation of

transmission system reliability. This move will require an overhaul of WECC and NERC reliability criteria and will require federal approval.

1. Assess the probabilities associated with all contingencies based on ten years of relevant historical outage data.
2. Identify the consequences of the contingency event (e.g., amount and duration of uncontrolled load loss, economic impacts of such load loss, public safety concerns).

Some may argue that a move to probability-based reliability criteria could result in lower reliability. But this argument assumes all contingencies are equally inconvenient and harmful for consumers. The reality is that different contingencies have significantly different consequences. A probability-based reliability approach would result in higher consumer welfare than the current deterministic criteria since (i) capital would be spent on contingencies where the combination of probability and consequence would otherwise provide the worst outcome for consumers, and (ii) capital would not be spent on contingency events that result in minor consumer inconvenience.

4.2.5 Adopt a Transparent Process for Developing Starting Point and Input Assumptions Used in the Reliability and Economic Study Models

A transparent process should be adopted to develop and obtain upfront stakeholder agreement on "starting points." Starting points include generation dispatch and forecast loads in the reliability models. In the economic models used evaluate and compare alternatives, starting points can include the range of major input assumptions such as load forecasts, gas prices, import levels and renewable generation development. No regulatory changes or approvals are necessary. The CPUC, CAISO or others could initiate and facilitate the process of obtaining stakeholder agreement.

Although this process may appear to lengthen the evaluation process early on, it should save a lot of time during the project approval process. The upfront agreed-upon range of major input assumption would save time by reducing substantially intervener questions related to the basis for the input assumptions, the appropriateness of those assumptions, and requests for multiple scenario runs under different assumptions (a very time consuming process).

4.3 Recommendation 3 – Modify the CAISO Generator Interconnection Process

4.3.1 Study Methodology Modifications

Eliminate the priority currently given to existing generation when evaluating the Delivery Network Upgrades that may be useful for consumers and for interconnecting generators. It does not make sense to assume all existing inefficient generation in the area of an interconnecting generator will be operating at high levels at the same time as more efficient new generation.

Some may argue that the older and less efficient existing generators were developed with the "expectation" of being able to deliver their energy to load under nearly all grid conditions and that allowing newer generators to use existing transmission capacity would reduce the existing generator's value (e.g., through reduced Resource Adequacy value). This argument is not valid. No generator is entitled to any particular level of profit. The possibility of new entry is an economic risk in every market. Electricity is no exception. Consumers are entitled to the economic consequences of competition between existing and new generation and regulatory policies should not discriminate against new entry. Eliminating this discriminatory treatment will require action by FERC.

4.3.2 Eliminate the Distinction between "Full Capacity" and "Energy Only"

The distinction between "Full Capacity" and "Energy Only" in interconnection studies should be eliminated and replaced with an interconnection study process that identifies contingency-based reliability criteria violations across a range of assumed interconnecting generation quantities in locations of interest.

1. Identify mitigation measures, including wires, operating solutions and/or non-wires solutions, for each reliability criteria violation identified across the range of interconnecting generation quantities studied.
2. Perform an economic evaluation among the identified mitigation measures. This evaluation would estimate the relative benefits and costs of each mitigation measure to consumers.
3. Based on the results of the economic analysis, let the interconnecting generators decide for themselves whether to finance none, some, or all of the identified Delivery Network Upgrades. This decision would be based on the interconnecting generators' own assessment of the amount of new generation that will ultimately get built in the area, the costs and difficulties of advancing funding for the identified upgrade, the potential economic rewards to the generator of the upgrade, and the likelihood that construction of the upgrade will be approved by the applicable regulatory authorities.

4. The entity that will ultimately own the Delivery Network Upgrade funded by the interconnecting generator should be required to demonstrate to the applicable regulatory authorities (e.g., the CAISO and the CPUC) why this infrastructure addition will be good for consumers compared to other alternatives (such as the tripping of generation for certain contingency conditions) since consumers will ultimately pay for the infrastructure addition.

4.4 Recommendation 4 - Regulatory Modifications

Regulators should be required to evaluate the economic reasonableness of the project sponsor's alternatives showing. This may require repealing section 399.2.5 of the California Public Utilities Code. The CPUC has already publicly stated that it believes the transmission project approval threshold provided by section 399.2.5 is very low. The IOUs will no doubt argue that section 399.2.5 must be retained in order to avoid time consuming "need" determinations for proposed transmission projects that are "needed" to meet aggressive renewable resource goals. But this is a circular argument since it assumes it is possible to establish that a proposed transmission project is "needed" to meet renewable resource goals without actually conducting a need assessment, i.e., without actually comparing the costs and benefits of the proposed project against the costs and benefits of alternatives that also meet renewable goals.

The CAISO should refile with the FERC for authority to require a CAISO Board determination that Delivery Network Upgrades costing more than $50 million will result in life-cycle consumer benefits (relative to feasible alternatives) that exceed the revenue requirements associated with the proposed project's cost. It is true that in 2005 the FERC declined to accept the CAISO's proposed economic evaluation methodology for network upgrades identified in new generator interconnection studies. However, the FERC did not specifically reject the CAISO's proposal but indicated that a more detailed proposal was needed. Based on recent FERC decisions it is clear that the FERC expects the CAISO to perform such evaluations. The CAISO needs to submit a more comprehensive economic evaluation methodology to the FERC.

Note that not every proposed transmission project needs to be subject to the same scope of economic scrutiny. In general, the scope of the analysis should be proportional to the economic risk that consumers will incur. Higher level economic analysis should be acceptable for projects with low cost and high expected benefits (relative to alternatives). Detailed economic analysis should be applied for projects with high cost and uncertain benefits (relative to alternatives).

5.0 Discussion

5.1 What Are the IOUs', Municipal Utilities', the CAISO, and Generation Developers' Incentives in Transmission Expansion?

5.1.1 Investor Owned Utilities

Profits for IOUs are calculated as a direct function of the amount of transmission investment that the owners can accumulate; the larger the capital investment, the greater the profits for the shareholders that own the IOUs. FERC authorizes a rate-of-return on transmission ratebase for each jurisdictional IOU. To increase profits IOUs therefore have an incentive—assuming they can raise the necessary capital—to increase their transmission ratebase by justifying large and costly transmission projects.[27] The IOUs can also rely on section 399.2.5 of the California Public Utilities Code to backstop transmission cost recovery if, for any reason, FERC denies recovery of prudently incurred costs.

5.1.2 Municipal Utilities

Non-investor owned utilities, e.g., municipal utilities, do not "profit" from increased transmission ratebase. Lacking any profit incentive, non-IOUs tend to be more focused on *minimizing* transmission costs, i.e., finding the alternative that provides the greatest net economic benefit to their consumers. However, non-investor owned utilities seem to have conflicting objectives. In California, many municipal utilities have shown resistance to turn operational control of their transmission facilities over to the CAISO. With the exception of municipal utilities that have joined the CAISO, municipal utilities will go to considerable effort--including the development of transmission expansion plans that duplicate CAISO facilities--to minimize their reliance on investor owned utility transmission and the CAISO's market-based open access paradigm.[28] Actual

[27] Averch and Johnson, 1960

[28] Much of the initial debate in California's RETI process centered around the municipal utilities' desire to create, through new infrastructure, municipal utility-owned transmission lines that would bypass CAISO-controlled transmission, creating a so-called "contract path." The fact that power flows are notoriously disrespectful of contract paths—i.e., that physical delivery of renewable energy from specific generators to specific loads on specific transmission lines is neither possible nor necessary in a network—seemed not to matter to the municipal utilities. RETI provides an example of such duplication: RETI's Phase 2A conceptual transmission plan includes two sets of substations at the Mountain Pass, Baker and Barstow CREZs, one set of substations connected to the LADWP balancing authority area and the other set of substations connected to new network transmission lines tied to the CAISO balancing authority area.

construction of duplicative facilities to the CAISO's is a more forward looking risk since the CAISO started operation in April 1, 1998.

5.1.3 Generation Developers

Generation developers may be required to finance massive network upgrades on IOU or municipal utility systems (for the most part, IOU and municipal utility interconnection procedures are similar). However, generation developers are repaid, with interest, by the IOUs or municipal utilities within five years of the generation project beginning commercial operation. Consumers ultimately pay for whatever network upgrades are built (via transmission rates paid to the utilities who reimburse the generation developers pursuant to section 12.3.2 of the Large Generator Interconnection Procedure (LGIP) - Appendix Y in the current CAISO tariff).

At the same time, the infrastructure addition could improve the capacity value of the developer's project, and, depending on the electrical location of the generator, reduce losses and potential congestion-related costs. Because a developer can improve the market value of its generating plant through new transmission with no net out-of-pocket costs for the new transmission, the developers' incentive—like the IOUs' incentive—lies with transmission expansion (presuming, of course, that the developer can get over the initial financing hurdle).[29]

Note that when an IOU reimburses the generation developer for the cost of building the network upgrade, the network upgrade costs are added to the transmission provider's rate base and the IOU's profits increase.

This is not to say that the renewable developers do not encounter many obstacles in their efforts to interconnect and obtain access to the grid. On the contrary, their right to access the grid, in many cases, is hampered by the challenge of funding large Delivery Network Upgrades identified by the CAISO and IOUs. In addition, generation developers are anticipating the negotiation of Purchase Power Agreements (PPAs) with the utilities. Accordingly, renewable industry representatives and developers have consistently supported large transmission infrastructure additions in different transmission planning and approval processes.[30]

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[29] A requirement to finance large and costly network upgrades favors the largest, most heavily capitalized, developers. This includes large energy companies and utilities. Smaller developers can be squeezed out regardless of how economic their project would otherwise be.

[30] See, for example, the November 13, 2008 report by the Community Alliance for the Sunrise Powerlink which reports on the appearance of the Chief Executive Officer of Stirling Energy Systems before the CPUC in support of the Sunrise Powerlink: *www.supportsunrise.com/downloads/news/12-Powerlink_Moves.pdf*. In the RETI process, renewable generation industry representatives provided strong support for building massive transmission loops around the southern California load centers. Other examples include renewable industry participation in the Tehachapi Collaborative Study Group and the

5.1.4 California Independent System Operator

In California, the IOUs (and half a dozen municipal utilities) must obtain approval from the CAISO in order to recover the costs of new transmission from CAISO consumers. Pursuant to CAISO Tariff section 24.1.1, the CAISO is charged—by the FERC—with the responsibility to independently evaluate proposed transmission projects to ensure that the projects are in the public interest and that the estimated and actual transmission investment costs are just and reasonable and are properly collected from consumers.[31] But what are the CAISO's incentives?

The CAISO's over-arching responsibility is to ensure that the grid continues to operate reliably. In very broad terms, more transmission means higher operating margins and possibly easier and—it is assumed—more reliable operations.[32] Wide-spread system failures are instantly inconvenient and extremely visible; a major system failure would reflect poorly on the CAISO and expose management and personnel to public excoriation and potential job loss.[33]

Because there is no tie between management compensation and the amount of costs included in the CAISO's Transmission Access Charge (TAC) mechanism, there is no incentive for the CAISO management to consider cost as one of the deciding criteria. The CAISO's transmission approval record shows that the CAISO has never turned down a major transmission expansion project proposed by the IOUs and routinely approves proposed transmission projects with little or no economic consideration of potentially feasible alternatives.

Imperial Valley Study Group and support for the transmission upgrades identified therein. Recurrent comments on RETPP Second Revised Straw Proposal 12/16/2009 urging the approval of the SCE Tehachapi transmission expansion project.

[31] CAISO Tariff section 24.1.1

[32] It is assumed that higher operating margins translate into a lower risk of system failure. However, most wide-spread system failures have been the result of poor maintenance and operator error and, depending on the circumstances, higher transmission margins may not protect against these failures.

[33] A recent event in San Diego underscores the extreme visibility of involuntary load loss. On April 1, 2010 nearly 300,000 homes and businesses were intentionally blacked-out for a short period of time, approximately 2 hours. While this event went unnoticed by most customers—they were sleeping—and appears to have been a minor inconvenience for most, it nevertheless attracted wide-spread media attention including a number of articles in the San Diego Union-Tribune. As of April 5, 2010, the events leading up to the outage are still being investigated, but there is already speculation that operator error was the root cause.

	Major transmission Expansion Projects Proposed to the CAISO	Approval Status
1	PG&E Jefferson-Martin	Approved
2	SDG&E Valley -Rainbow	Approved
3	Nevada Hydro TE-VS	No decision yet
4	SDG&E Miguel-Mission #2 line	Approved
5	Transelect Path 15 Upgrade	Approved
6	Transbay cable	Approved
7	SDG&E Valley-Rainbow	Approved
8	PG&E Los Banos-Gates	Approved
9	PG&E Portrero-Hunter Point	Approved
10	SDG&E Otay Mesa Power Purchase Agreement Transmission Project	Approved
11	PG&E Tri-Valley Capacity Increase Project	Approved
12	SDG&E Sunrise Powerlink	Approved
13	SCE Tehachapi Segment 1	Approved
14	SCE Tehachapi Segments 2-11	Approved
15	SCE Palo Verde-Devers #2	Approved
16	SCE Colorado River–Devers-Valley #2	No action yet, pending inclusion in an LGIA
17	Path 45 upgrades	Approved
18	SCE Ivanpah-El Dorado	No action yet
19	Green Energy Express	No action yet

According to a recent report by the C-Three Group, over the last ten years, the ISO has approved approximately $8 billion in transmission upgrades, half of which are under construction or in-service. The CAISO obtains most of its operating funds from the IOUs. The CAISO's role as an advocate for transmission infrastructure additions is inherently inconsistent with its responsibilities as a regulating body and in conflict with its obligations to consumers. This, unfortunately, has proven to be quite problematic for the objective evaluation and approval of transmission projects in California as both federal and state regulators rely heavily on the analysis and recommendations of the CAISO.

5.2 Where Does the Perception of a Transmission Shortage Come from and Is It True?

5.2.1 Perception

Delays in the generation interconnection process, coupled with the inability of many renewable resource developers to obtain environmental permits and funding, have, over time, contributed to the perception that (i) a serious transmission shortage exists in the country and in California, and (ii) that this shortage is the cause of the delay in renewable generation development and in meeting California's renewable generation goals.[34] This perception has put tremendous pressure on regulators and government agencies to approve more transmission infrastructure additions, and at much faster pace.

While the blame for some interconnection delays can be traced to renewable developers' lack of technical expertise and unfamiliarity with the transmission study process, transmission owners have limited incentives to improve the interconnection process. Slowing down renewable development carries two benefits. First it leaves the impression that there is not enough available transmission capacity to connect new renewable generation to the grid and therefore, more and larger transmission expansion projects (i.e., "super highways") are needed. Both RETI and WGA WREZ initiative—which are transmission building initiatives in California and in the Western United States respectively—have predicated their efforts on the basis that building "more transmission" would solve the problem of getting more renewable energy on line faster. Second, since delay in transmission development is a convenient excuse for load serving entities' failures to meet their renewable energy goals.

5.2.2 Does the Data Support the Perception of a Transmission Shortage?

As the following table illustrates, California's IOUs have been adding transmission investment to their transmission ratebase at a pace that far exceeds the underlying growth in consumer energy demand.[35] Any claim that transmission expansion has been at a virtual standstill over the last decade is not borne out by the amount of money that is being spent, at least not in California.

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[34] CEC RETI website: "Extensive improvements, however, are needed to California's electric transmission infrastructure to get the electricity generated by new renewable power facilities to consumers."
The Western Governors' Association (WGA) Western Renewable Energy Zones (WREZ) - Phase 1 Report states that the "lack of cost effective transmission access was, and remains, the greatest impediment to the rapid development of utility-scale, renewable-rich resource areas."

[35] The transmission ratebase and energy loads for individual IOUs are shown in Appendix 1.

Table 4. Total California Investor Owned Utilities Transmission Investment and Net Energy				
	Transmission Investment	Growth Relative to End of Year 1998	Net Energy for Load (gWh)	Growth Relative to 1999
1999	$6,176,427,571	1.00	214825.6449	1.00
2000	$6,419,919,050	1.04	227310.3264	1.06
2001	$6,633,249,346	1.07	211812.1949	0.99
2002	$6,884,425,725	1.11	214230.1894	1.00
2003	$7,223,722,052	1.17	218315.7727	1.02
2004	$7,860,532,912	1.27	226170.826	1.05
2005	$8,458,936,491	1.37	227787.1251	1.06
2006	$9,078,342,234	1.47	234834.3519	1.09
2007	$10,024,390,899	1.62	239540.1637	1.12
2008	$10,772,945,550	1.74	243841.741	1.14
2009	$11,371,199,873	1.84	235093.247	1.09

Notes: Transmission Investment column shows the approved portion of transmission investment in the transmission rate base for each year yet to be recovered from the customers. Transmission Investment values are from FERC Form 1. The 2009 values are estimated. Energy loads are from the CEC's 2009 adopted Integrated Energy Policy Report.

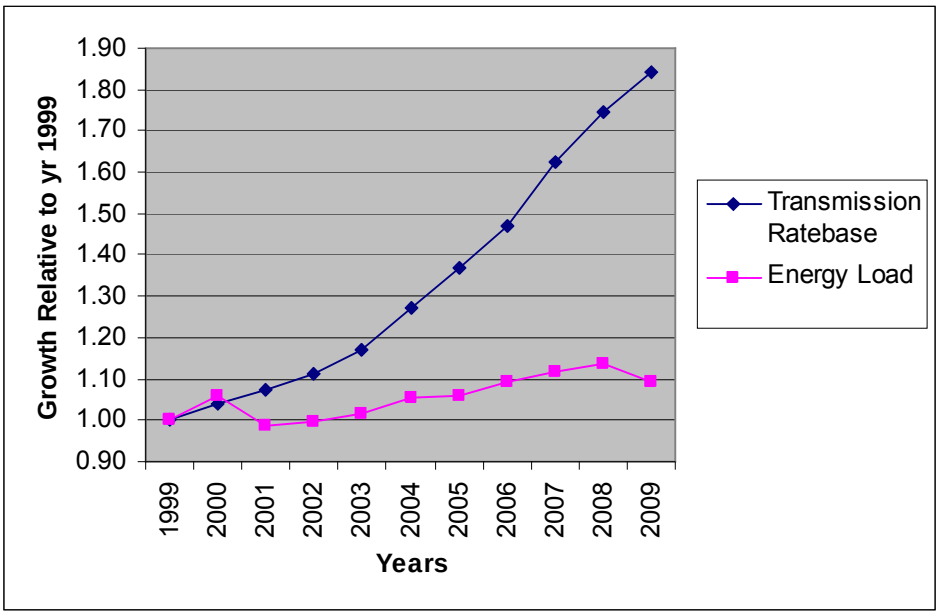
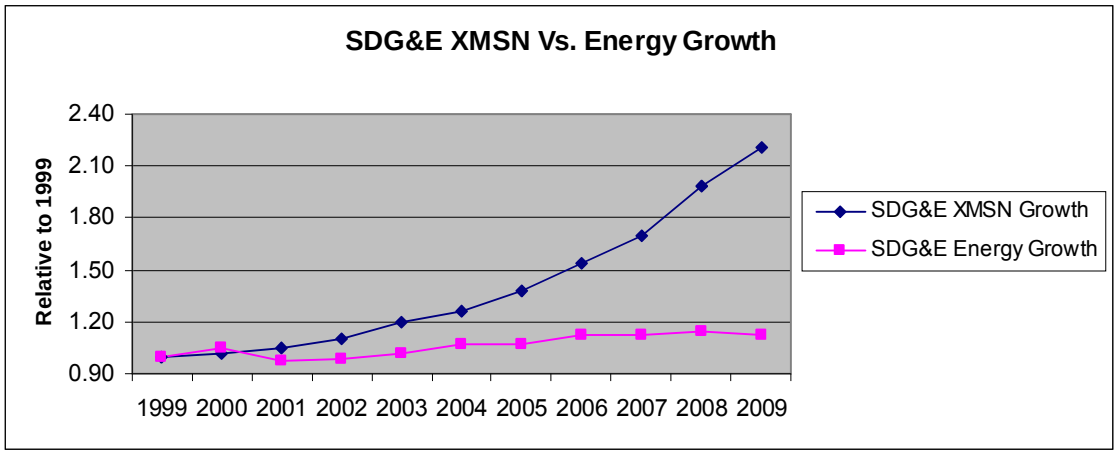
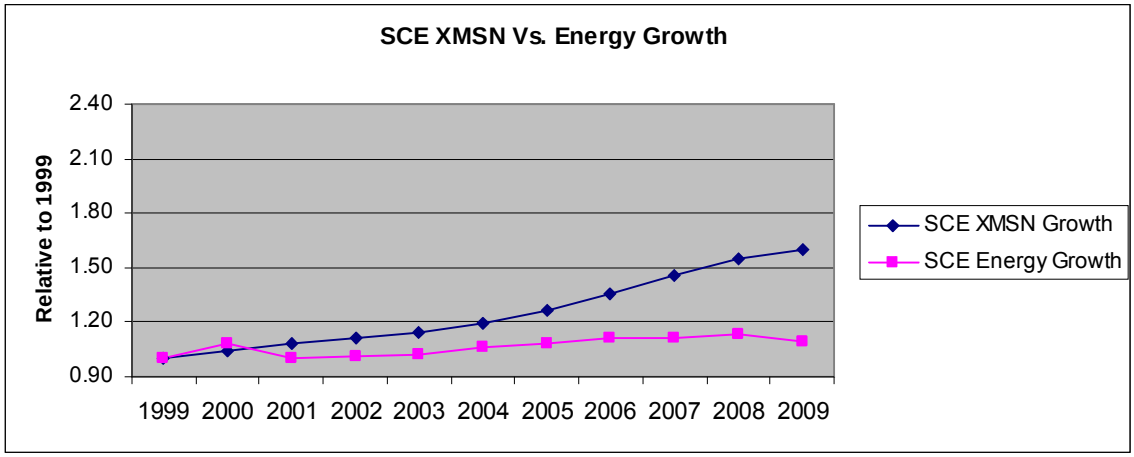
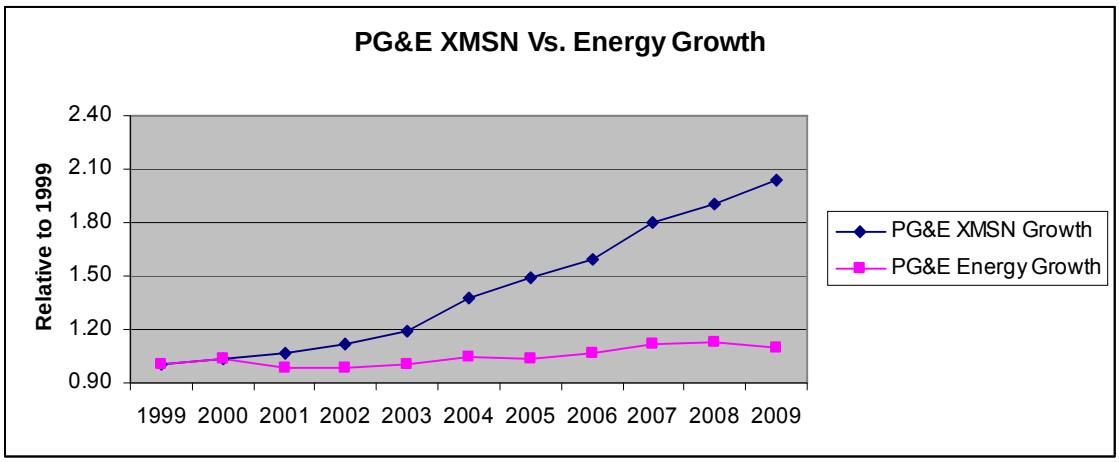


Table 5. Transmission and Energy Growth						
	SDG&E	SDG&E	SCE	SCE	PG&E	PG&E
	XMSN Growth	Energy Growth	XMSN Growth	Energy Growth	XMSN Growth	Energy Growth
1999	1.00	1.00	1.00	1.00	1.00	1.00
2000	1.02	1.05	1.04	1.09	1.04	1.03
2001	1.05	0.97	1.08	1.00	1.07	0.98
2002	1.11	0.99	1.11	1.01	1.12	0.99
2003	1.19	1.02	1.15	1.03	1.19	1.01
2004	1.26	1.07	1.19	1.06	1.37	1.04
2005	1.38	1.07	1.26	1.08	1.49	1.04
2006	1.53	1.12	1.35	1.11	1.59	1.07
2007	1.70	1.13	1.46	1.11	1.80	1.11
2008	1.98	1.15	1.55	1.14	1.91	1.13
2009	2.21	1.12	1.59	1.09	2.04	1.09







5.2.3 What's Next?

Looking ahead, if currently proposed transmission lines are actually built, the size of the IOUs' ratebase will swell. Today, transmission project sponsors seeking CAISO approval typically assert that their projects meet at least one of three bases for approval: "reliability," "economics," or "renewables." (Later in the paper there is a a discussion pointing out that these distinctions are meaningless, that all proposed network transmission projects support grid "reliability," that all proposed network transmission projects facilitate the development of "renewable" resources, and that all proposed network transmission projects should be "economic" relative to alternatives.) Renewable resource development goals and greenhouse gas reduction targets set by federal and state agencies are being used by transmission developers to justify many large and expensive transmission expansion proposals under the "renewable" approval category.

Recently the CAISO initiated a stakeholder process, the Renewable Energy Transmission Planning Process (RETPP), to consider tariff revisions which would formally create a renewable transmission project approval category outside of the current

generator interconnection process.[36] According to the CAISO's proposal network transmission additions that are "needed" to "access" renewable resources in an area with sufficient commercial interest could be approved by the CAISO Board with no economic analysis of viable alternatives. Under these approval criteria every proposed network upgrade would qualify since every transmission project in a network supports the movement of power from generation to load and therefore provides some level of "access" to every area with commercial interest in renewable generation. If FERC approves the proposal, the CAISO would be relieved of any statutory obligation to evaluate whether proposed network upgrades that can be associated with an area that has demonstrated commercial interest in renewable resource development, are economic relative to other feasible alternatives.

While the rapid increase in transmission rates over time should be alarming, the amount of future transmission now in the implementation and approval pipeline could make historical transmission rates look quite modest. Focusing on California, there have been a number of recent transmission planning activities that have identified a long list of new transmission projects. RETI, CAISO, and CTPG have independently developed these lists.

The RETI and CAISO cost figures do not include the cost of major transmission projects such as the Sunrise Powerlink and the Tehachapi Segments 1-3 projects. These estimates do not include the costs of numerous transmission expansion projects that are considered to be unrelated to renewable resource development (e.g., projects that are considered to be needed for local "load growth"). Projects associated with renewable resources that have already received CAISO approval could add an additional $2.2 billion to the total costs.[37] Furthermore, it appears the transmission cost estimates included in the RETI Phase 2A report are significantly understated. For one thing, the RETI Phase 2A estimates contain no land costs. For another thing, a comparison between the unit-cost derived estimates in the Phase 2A report with the corresponding project costs in regulatory proceedings suggests the RETI cost estimates are significantly understated.

Detailed cost estimates for some of the projects in the RETI Phase 2A conceptual transmission plan have been developed and used in formal regulatory proceedings. For

[36] According to the CAISO's Draft final RETPP proposal dated January 6, 2010, "the primary driver of new transmission infrastructure over the coming decade will be the need to integrate new renewable generation resources into the transmission grid and support the delivery of energy from these resources to end-use customers to achieve the state's target of 33 percent renewable energy on an annual basis by 2020." (page 3) The right to build and own those projects is reserved—via existing and proposed Right of First Refusal (ROFR) provisions in the CAISO tariff—to existing utilities with distribution service areas.

[37] Sunrise $1.883 billion (Ordering paragraph 6, page 293 of D.08-12-058 dated 12/18/2008), Tehachapi Segment 1-3: actual costs of almost $400 million, per SCE filing in FERC docket ER10-160 (CWIP).

example, The Nevada Hydro Company's application at the CPUC for a CPCN for the Talega-Escondido/Valley-Serrano project included a cost estimate of about $353 million.[38] The RETI Phase 2A conceptual transmission plan estimated the same facilities at $162 million,[39] low by more than a factor of two. Comparing the cost caps included in CPUC decisions with RETI's Phase 2A estimates reveals similar discrepancies: Tehachapi Segments 4-11 ($1.785 billion vs. $0.962 billion) and Colorado River-Devers-Valley #2 ($536.6 million vs. $490.75 million)[40]. If this difference is applied to every transmission element included in the RETI Phase 2A conceptual transmission plan, California would be looking at about $30 billion (in today's dollars) in additional new transmission infrastructure cost ostensibly needed to reach a 33% renewable goal. (This compares to the IOUs' current combined ratebase of about $11.4 billion.) Using a factor of 10% to convert estimated capital costs into levelized annual revenue requirements, annual costs to consumers could be increased by $3 billion per year.

In addition, there has been an explosion of proposed bulk power inter-regional transmission projects. Many of these projects are intended to move power from the outer reaches of the WECC to the California load centers.[41] At this juncture, it is not clear how much of the costs of these projects will be directly borne by California consumers, but it is certain that consumers somewhere will be on the hook for billions of dollars in new transmission costs should any of these projects actually get approved and built.

The amount of proposed transmission in various stages of regulatory approval is enormous. It includes upgrades within the CAISO balancing authority as well as interstate transmission projects that cross multiple balancing authority areas. Project proponents are asserting that these upgrades are needed to meet renewable resource goals, yet, for most of these proposals, no serious attempt has been made to show that the proposed projects are economically superior to non-wires alternatives that rely on existing grid transfer capability to meet renewable resource goals.

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[38] Page 25 of D.09-11-007 dated November 20, 2009.

[39] RETI Phase 2A Final Report, September 23, 2009, Table 1-1. Also, see Appendix A to this paper.

[40] Cost of Tehachapi Segments 4-11: $1.785 billion ($1.162673 billion for direct costs (page 68) + $0.185857 billion for Pension & Benefits and A&G (page 68) + $0.1744 billion for contingencies (page 72) + $0.26182 for AFUDC (page 73)), D.09-12-044 dated 12/17/2009 versus Tehachapi Segments 4-11: $0.96161 billion, Appendix H of RETI's Phase 2A final report dated September, 2009 (excludes right-of-way costs).

Cost of Colorado River-Devers Valley #2: $536.6 million -- 2009$ (page 25 of D.09-11-007 dated November 20, 2009) versus $490.75 million (Appendix H of RETI's Phase 2A final report dated September, 2009) (excludes right-of-way costs).

[41] A partial list of interstate transmission project proposals is provided in Appendix E to this paper.

5.2.4 Why Should Anyone Care?

Unnecessary transmission is economically wasteful, creates unnecessary adverse environmental impacts (e.g., permanent visual impacts, consumes land that may be valuable for other uses), and impedes progress towards carbon emission reduction goals by diverting capital away from technologies that are effective in reducing carbon emissions. Conversely, economically sound transmission investment saves consumers money, allows existing inefficient fossil-fired generation with high emission profiles to be shut down,[42] and provides more capital for building renewable generation that will reduce air emissions. The public, and regulators responsible for protecting the public interest, have a direct stake in the outcome of every proposed transmission project.

Because transmission costs are spread across millions of consumers over long periods of time, consumer sensitivity to increases in transmission costs has tended to be muted. Wide-spread consumer alarm to the rapid build-up of transmission ratebase has not materialized. There has been strong consumer opposition to specific transmission expansion projects, but the dominant element of most of this opposition has been environmental concerns. In addition, such opposition is almost always localized among consumers that are in geographic proximity to the proposed projects.

While local opposition is understandable, all CAISO consumers are affected by such upgrades since each consumer will pay a load-weighted share of the costs of every transmission upgrade. The costs of the high-voltage transmission system under the operational control of the CAISO (facilities operated above 200 kV) are socialized across all CAISO consumers through the CAISO's Transmission Access Charge (TAC) mechanism. All consumers are therefore affected by the transmission investment decisions made by every transmission owner who has turned operational control of its facilities over to the CAISO (this includes SCE, SDG&E, PG&E and a number of municipal utilities in southern California). For example, the transmission investments made by SCE are paid in part by SDG&E's customers and the transmission investments made by SDG&E are paid in part by SCE's customers. The important point here is that the economic effects of poor transmission investment decisions are not contained to where the transmission line is located; they are spread broadly across most of California's consumers.

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[42] All network transmission upgrades will carry both renewable and fossil-fired generation. This is an inevitable consequence of physics since there is no way for the transmission network to distinguish between renewable electrons and fossil-fired electrons. Accordingly, regulatory policies intended to promote reductions in greenhouse gas emissions should focus on resource procurement strategies, not transmission approval criteria. New transmission that reduces grid congestion will have beneficial impacts on greenhouse gas emissions because it will allow the most efficient fossil-fired generation (which has relatively low emission profiles) to displace the least efficient fossil-fired generation (which has relatively high emission profiles).

Once a transmission upgrade project is approved and built, the money has been spent. There is no getting it back if it turns out the transmission upgrade was unnecessary or under-utilized. It is imperative, therefore, that decisions to upgrade the grid be based on objective determinations of whether a "need" exists in the first place, and if so, sound analysis of a broad range of feasible alternatives that would address the identified need. For instance, it would not make sense to spend billions of dollars on new transmission infrastructure to facilitate the development of renewable resources in remote areas if it is determined that public policy goals could be met more cost-effectively by using this money as incentives for expanded energy efficiency and/or distributed generation applications that reduce renewable resource requirements to levels that do not require the new infrastructure.

5.3 Does Existing Regulatory Oversight of Proposed Transmission Protect Consumers?

Transmission expansion decisions start long before approval authorities are asked to render a final decision. It begins in the planning process when transmission providers size up future needs and identify options for meeting those needs. Determining what actually constitutes a "need" is the first thing that requires scrutiny.

As profit-driven entities, IOUs have strong reasons to find creative ways to find a "need" for new transmission. Once a "need" for transmission is identified, attention is focused on which transmission addition will meet that need, and not on the threshold question of whether any transmission additions are needed in the first instance.

The transmission approval process for Investor Owned Utilities in California requires FERC's approval of the cost recovery structure (including authorized rates of return), the CAISO's approval that the project is in the public interest (that costs CAISO consumers are estimated to incur if the project is built will be offset by benefits that CAISO consumers are projected to realize), and the CPUC's determination that the project is "needed" and can be constructed without unacceptable adverse environmental impacts. Finally, for projects that are constructed, the FERC must formally accept the actual costs for inclusion in consumer rates. Both the CPUC and the FERC weight heavily the CAISO's evaluation and recommendation for their respective approval decisions. This makes the role of the CAISO in the approval process crucial.

Proposed transmission projects identified on the basis of load growth are usually designated and approved as "reliability" projects under the theory that the load must be served and that there are no practical options for serving the load other than to build the proposed transmission project. The CAISO tariff does require that the CAISO "consider lower cost alternatives…such as acceleration or expansion of existing projects, Demand-

side management, Remedial Action Schemes, appropriate Generation, interruptible Loads or reactive support." (Section 24.1.2) "Lower cost," however, is not the sole appropriate test because alternatives can have a lower cost, yet still provide little in the way of consumer benefits.

Before concluding that there are no practical alternatives to building new transmission in order to meet projected load growth, planners should be required to make an affirmative determination that a reasonable range of non-wires alternatives were considered and found to be are economically infeasible or impractical for other reasons. Such alternatives include expanding energy efficiency and other demand response programs and adding distributed generation such as rooftop solar photovoltaic. In certain situations it may be possible to develop Remedial Action Schemes (RAS) that open otherwise overloaded network facilities in response to critical contingencies, thereby allowing the load to be met without the need for new transmission. In some instances developing new generation closer to the load may be a cheaper and environmentally more desirable alternative than building a long and expensive transmission line.

The examination of FERC's recent record shows once a transmission expansion project is approved by the CAISO, there is little risk that the FERC will second-guess the inclusion of associated costs in consumer rates.

5.3.1 Did the CAISO Perform Due Diligence in Approving the Tehachapi Segments 2-11 Project and in Evaluating the Colorado River-Devers-Valley #2 Project?

The ability of the CAISO to approve Delivery Network Upgrades without any economic evaluation against alternatives arises out of a 2005 FERC decision[43] that declined to approve the CAISO's proposed economic evaluation methodology for network upgrades identified in new generator interconnection studies. The CAISO's existing transmission project approval processes are, unfortunately, within the legal boundaries set by the FERC.

In the case of the proposed Tehachapi Segments 2-11 projects (a $1.785 million project), the CAISO Board approved the projects without any consideration of alternatives that might have mitigated the identified reliability criteria violations at an order of magnitude lower cost to consumers (e.g., operating procedures that would trip generation in the event of unlikely outages). In the case of the Colorado-Rivers-Valley #2 project (a $536.6 million project), there will be no CAISO Board review or decision because the CAISO has decided to treat the proposed project as a Delivery Network Upgrade. The CAISO's existing tariff provides for automatic approval of Delivery

[43] Id 18

Network Upgrades via a simple CAISO management signature on one or more Large Generation Interconnection Agreements (LGIAs) which list the Delivery Network Upgrade as "needed." Delivery Network Upgrades are identified in generator interconnection studies which use a conservative study methodology, improbable study assumptions, and require no economic evaluation of alternatives. (Delivery Network Upgrades are described further in the discussion of interconnection issues.) There is no way to know whether an identified Delivery Network Upgrade is actually the best choice for consumers.

Nowhere does the CAISO evaluate other non-infrastructure options for mitigating whatever reliability criteria violation it identified. For example, would it be more economical to simply reduce the output of certain fossil-fired generators under certain conditions to mitigate this adverse outcome and thereby avoid the cost of building the new line altogether? Or could generator tripping and/or controlled load drop schemes be put in place at a lower cost? Would additional reactive support be effective in mitigating whatever reliability criteria violation the CAISO found?

Even in the case of the Sunrise Powerlink project where some economic analysis of alternatives took place, the CAISO failed to perform due diligence. For example, the majority of the economic benefits estimated by the CAISO for the recently-approved Sunrise Powerlink project are based on the benefits associated with reducing the amount of local generating capacity that San Diego area load serving entities are required to place under contract in order to satisfy the San Diego area Local Capacity Requirement (LCR). However, in the CPUC proceeding evaluating the economics of the project it was the CPUC's Division of Ratepayer Advocates who initially pointed out that the CAISO had conducted studies outside the Sunrise Powerlink proceeding indicating that with the addition of the Sunrise Powerlink, there would be no immediate decrease in the amount of generating capacity that San Diego area load serving entities would be required to place under contract in order to satisfy local capacity requirements. The addition of the line creates a new Greater Imperial Valley-San Diego LCR area with exactly the same magnitude of local capacity requirements as the San Diego LCR area would have in alternatives without the Sunrise Powerlink. (A discussion of adequacy of the economic analysis performed in the Sunrise Powerlink proceeding is outside the scope of this paper.)

It is not known whether the failure of the CAISO to account for the costs of the Greater Imperial Valley-San Diego LCR area was intentional, but it is the CAISO's responsibility to provide a thorough and careful analysis of the costs and benefits of projects proposed by the IOUs, and to provide independent recommendations to other

approval authorities, particularly when other regulating bodies rely heavily on the CAISO's analysis and recommendations.

5.3.2 What about CPUC Oversight of Proposed Transmission Projects?

In separate decisions the CPUC has approved Certificates of Public Convenience and Necessity (CPCNs) for the Tehachapi Segment 1 project, the Tehachapi Segments 2-3 project, the Sunrise Powerlink project, the Tehachapi Segments 4-11 project and, on a conditional basis, the Colorado River-Devers-Valley #2 project. With the exception of the Sunrise Powerlink no project was subjected to an economic comparison against other alternatives; i.e., there was no determination that the approved projects were economically superior to other wires alternatives, operating procedures, and/or non-wires alternatives.

In the Tehachapi Segment 1 project, the Tehachapi Segments 2-3 project and the Tehachapi Segments 4-11 project, currently called Tehachapi Renewable Transmission Project (TRTP), the CPUC invoked section 399.2.5 of the California Public Utilities Code as the basis for approving the projects without any economic evaluation against viable alternatives. Section 399.2.5 requires the CPUC to issue a finding of "need" so long as the proposed project is "necessary to facilitate achievement of" Renewable Portfolio Standard (RPS) goals, a test which the CPUC itself admits is "a low threshold." This provision of the California Public Utilities Code is being used by the IOUs and by the CPUC to avoid the difficult and often contentious evaluation that would otherwise be required to demonstrate that consumers will be economically better off with the proposed transmission project than with other alternatives.

The Tehachapi Segments 1-11 project, which includes both radial and network transmission lines, has an estimated cost of about $2 billion.[44] These projects were approved by both the CAISO and the CPUC without any economic comparison of the network elements of the proposed projects against other feasible alternatives. The CAISO's decision to approve the Tehachapi Segments 2-11 project was based on the January 18, 2007 memo from CAISO management to the CAISO Board. The memo's recommendations are based on the December 29, 2006 report entitled *CAISO South Regional Transmission Plan for 2006 (CSRTP-2006) Part II: Findings and Recommendation on the Tehachapi Transmission Project.*[45]

[44] From the January 18, 2007 memo from CAISO management to the CAISO Board. This memo is available at *www.caiso.com/1b6b/1b6bb5ca7400.pdf.*
[45] Available at *www.caiso.com/18db/18dbaedf2cca0.pdf.*

But this report contains no assessment of how the costs and benefits of the network segments of the proposed Tehachapi Segments 2-11 project[46] compare to other potential alternatives for accommodating the development of renewable resources in the Tehachapi area. In fact, the section on economic benefits, section 4.3, constitutes a single sentence: "Significant economic benefits are expected as the Tehachapi Transmission Project provides access to renewable and efficient generation projects slated in the TWRA [Tehachapi Wind Resource Area]." The public, and apparently the CAISO Board, is simply left to guess at what this expectation is based on.

The CPUC then followed suit by granting SCE, without any economic analysis to support the CPUC decisions, three separate Certificates of Public Convenience and Necessity (CPCN) to construct the project.[47] CPUC D.07-03-012 was issued on March 1, 2007 and states that "no one has proposed a meaningful alternative to the project."[48] (Page 17) The decision repeats the statements in a January 10, 2007 affidavit by SCE's Gary Allen: "Without Segments 1, 2, and 3, SCE can use none of this renewable generation to serve California load." (Page 14)

CPUC D.07-03-045 which was issued on March 15, 2007,[49] states that:

> "Because SCE is obligated to allow connection of new wind projects to its system, upgrades must be implemented to mitigate identified overload of the Antelope-Mesa transmission line in order to maintain system reliability as required by the National Electric Reliability Council (NERC) and the Western Electric Coordinating Council (WECC) planning standards as well as the ISO planning standards." (Page 19)

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[46] Some elements of the Techachapi Segments 1-11 projects are radial so the question of alternatives for those facilities may be of less interest. However, much of the Tehachapi Segments 1-11 projects involve upgrades to the existing transmission network, so the relative economic costs and benefits of alternatives should be of great interest to those regulatory entities charged with protecting consumers.

[47] Under section 399.2.5 of the Public Utilities Code, the CPUC "must find that a project is needed when it finds that the project is 'necessary to facilitate achievement of' the RPS goals." (page 10 of D.07-03-012 and page 11 of D.07-03-045.) In both decisions, the CPUC observes wryly that:

> "to Merriam-Webster, that would mean 'to make easier' or 'to help bring about'. As long as a proposed line would connect the grid with an area capable of producing renewable power, it is hard to imagine that it would fail to clear such a low threshold." (page 15 of D.07-03-012 and pages 14-15 of D.07-03-045)

Nevertheless, there is nothing that prevents the CPUC from insisting that an economic analysis of viable alternatives be undertaken to determine whether the proposed project makes economic sense or whether it is a thinly-disguised attempt to pick consumers' collective pockets.

[48] Tehachapi Segment 1: *http://docs.cpuc.ca.gov/published/FINAL_DECISION/65273.htm*
[49] Tehachapi Segment 2-3: *http://docs.cpuc.ca.gov/PUBLISHED /FINAL_DECISION/65666.htm*

The decision never explores the possibility ("alternative") of mitigating the identified overload through operating procedures such as tripping generation for the contingencies which presumably create the referenced overload. NERC and WECC planning standards allow the use of such operating procedures. Given the short duration of most transmission line outages—a few hours at most—the economic consequences of cross-tripping some amount of generation is likely to be small, especially compared to the cost of building network transmission infrastructure upgrades. Given these options it is unclear how Mr. Allen came to the conclusion that without the Tehachapi Segment 1-3 project, SCE would be able to use exactly "none" of the renewable generation in the Tehachapi area.

D.07-03-045 wraps up by finding that:

> "Based on the foregoing uncontroverted evidence, we conclude that the Tehachapi-Vincent Transmission Project is needed to meet the demands of electricity customers south of Antelope Substation by increasing the capacity of the SCE system to a level that would accommodate proposed or planned wind energy projects, and there is no feasible alternative to the proposed project that can meet this need." (Page 20)

On December 17, 2009 the CPUC approved a CPCN for Tehachapi Segments 4-11 (D.09-12-044). This decision notes that section 399.2.5 provides that "a finding that the Project is necessary to achieve the state's RPS goals will serve as a definitive determination of need…and will render further consideration of need based upon reliability or economic factors moot." The CPUC has fashioned its own interpretation of what it takes for a proposed transmission project to be deemed needed under section 399.2.5. Specifically, the CPUC has decided that it needs to determine:

> "(1) that a project would bring to the grid renewable generation that would remain otherwise unavailable; (2) that the area within the line's reach would play a critical role in meeting the RPS goals; and (3) that the cost of the line is appropriately balanced against the certainty of the line's contribution to economically rational RPS compliance." (Page 9)

In D.09-12-044, the CPUC addresses each of these three tests. The CPUC's review of the three tests includes no discussion of whether the proposed project is economically superior to other feasible alternatives. With respect to the first test the CPUC relies on the CPUC Division of Ratepayer Advocates claim that "…without additional transmission capacity beyond the 700 MW provided by the ATP [Antelope

Transmission Project], 1590 MW of renewable generation would otherwise be unavailable if the Project was not constructed." (Pages 13-14) The CPUC makes no effort to determine—or even ask the question—of whether, for example, the implementation of a generator tripping scheme would permit some or all of the 1590 MW to be "available."

For the second test the CPUC simply relies on CPUC-approved purchase power contracts in the Tehachapi area, and on the increased transfer capability provided by the project, to conclude "…that the area within the Project's reach plays a critical role in meeting California's RPS goals." (Page 15)

For the third test—where the possibility of considering potentially economic alternatives seems most likely—the CPUC relies on (i) the CAISO's approval of the project, (ii) the CEC's 2007 Strategic Transmission Investment Plan Commission Report that found the project to be "one of five strategically important" transmission projects, (iii) the RETI Phase 1B report's finding that the Tehachapi area is "one of the most economically viable locations for providing new renewable resources with minimal environmental impacts," and (iv) a favorable comparison of the capital cost of the proposed project to the capital cost of the Sunrise Powerlink, to reach the conclusion that the "cost of the Project is appropriately balanced against the certainty of the line's contribution to economically rational RPS compliance." (Pages 17-18)

The CPUC's conclusion that the third test is met, fails on all points: The CAISO's approval of the project did not rely on an economic comparison against feasible alternatives. The CEC's report did not investigate the relative economic merits of alternatives. The RETI Phase 1B report did not evaluate alternatives for accommodating renewable generation in the Tehachapi area and, by its own admission, accepted SCE's determination that the capability of the existing grid to accommodate such renewable development was "zero."[50] And, comparing the capital costs of two different transmission projects without evaluating the comparative benefits those two projects provide, is mostly meaningless and certainly does not reveal anything about potential alternatives to the network elements of the Tehachapi Segments 4-11 project.

Nevertheless, CPUC D.09-12-044 finds "…that the Project is necessary to facilitate achievement of the renewable power goals set forth in § 399.11 et seq. Hence, under § 399.2.5, the Project is deemed to be necessary." (Page 18) "Economically

[50] RETI Phase 1B Final Report: "RETI first assessed the existing transmission system to determine the available capacity prior to adding additional capacity on the system. To identify the current available transfer capability (ATC) of the CAISO-controlled grid, RETI used Year 2007 Transmission Ranking Cost Report (TRCR) information prepared by California IOUs. In these reports the IOUs identify levels of ATC on their respective systems and estimate the upgrade costs to develop this transmission capacity. RETI included all 'zero-cost' ATC identified by the IOUs in the base case…. Per the TRCR, SCE identified no 'zero-cost' ATC." (Page 3-16)

rational RPS compliance" apparently does not require a determination that a proposed transmission project is economic relative to alternatives.

The conclusion in D.07-03-045 that "there is no feasible alternative to the proposed project" is surprising considering that there is not even a passing reference to the possibility of using operating procedures—such as cross-tripping generation—to ensure that the electric system can integrate additional renewable generation in the Tehachapi area and reliably and safely meet the demands of electricity customers. It would be interesting to know whether the project proponent's application for CPCNs for the Tehachapi Segments 1-11 projects even mentioned the possibility of using operating procedures as alternatives to some or all of the network elements included in the proposed projects. Given the IOUs' incentives to add ratebase, it is doubtful.

Of course, it might well be the case that the Tehachapi Segments 1-11 projects are a more economical way to accommodate the development of renewable resources in the Tehachapi area than other viable alternatives. But consumers will never know because such an analysis was never undertaken. The regulatory authorities responsible for approving the project—the CAISO Board and the CPUC Commissioners—never insisted that such an analysis be conducted.

A similar outcome appears likely for the California portion of the proposed Palo Verde-Devers #2 project. The full Palo Verde-Devers #2 project (actually Palo Verde-Devers-Valley #2) was initially approved by the CAISO and CPUC based on an economic evaluation that concluded consumers would be economically better off with the project than without the project.

After the Arizona Corporation Commission denied permission to build the Arizona portion of the project, the project was reconstituted as a California-only Midpoint-Devers-Valley #2 line (later called the Colorado River-Devers-Valley #2 project). The project sponsor petitioned the CPUC to modify its decision granting a CPCN to build the full Palo Verde-Devers #2 project. The project sponsor asked the CPUC to revise the decision so that the CPCN would provide the project sponsor with approval to build the Colorado River-Devers-Valley #2 line. In support of its petition, the project sponsor submitted information showing a high level of developer interest in building new generation in the eastern Riverside County area (in proximity to the proposed Colorado River substation).

Given the significant change in project scope, the CAISO withdrew its earlier approval of the full Palo Verde-Devers #2 project, contending, in a June 19, 2009 letter to the CPUC, that the CAISO's economic evaluation was "no longer applicable." However, the CAISO indicated that if more than 1030 MW of new generation were to be interconnected at the proposed Colorado River substation, there would be a "need" for

the proposed Colorado River-Devers-Valley #2 line (as a "generation interconnection facility") "in order for the generation from those facilities to be fully deliverable."

The CAISO submitted an October 19, 2009 letter to the CPUC pointing out that generation interconnection facilities do not require "express approval by the ISO's governing board." What is significant about this statement is that the CAISO is acknowledging that its approval of the Colorado River-Devers-Valley #2 line will be made via CAISO management's signature on a Large Generator Interconnection Agreement that identifies this line as a "needed" Delivery Network Upgrade. Under existing CAISO tariff provisions, the CAISO Board, which should be exercising independent oversight of the CAISO's activities, has no formal approval role for a project that is estimated to cost $536.6 million to build.[51] Interestingly, section 24.1 of the CAISO tariff states that "the determination of need by CAISO management for transmission additions or upgrades with an estimated capital cost of $50 million or more must be approved by the CAISO Governing Board." Apparently the provisions of the LGIA trump the provisions of CAISO tariff section 24.1.

The CAISO's comments to the CPUC do not provide the technical analysis supporting the CAISO's conclusion that if more than 1030 MW of new generation were to be interconnected at the proposed Colorado River substation, the proposed Colorado River-Devers-Valley #2 line would be "needed." It appears that this conclusion was reached by applying the deliverability analysis that forms the basis of the CAISO's generator interconnection study process. While the CAISO never provided any details of its analysis, it apparently found the amount of new generation interconnecting at the Colorado River substation that, if operating simultaneously with an assumed level of imports from Palo Verde, would result in a reliability criteria violation for a specified contingency condition (e.g., identifying the contingency condition under which, with this amount of new generation, there would be grid instability).

The CAISO's comments to the CPUC provide no information on whether the value of the "deliverability" that the Colorado River-Devers-Valley #2 line would provide to interconnecting generators—i.e., the potential ability to be counted towards a CAISO load serving entity's Resource Adequacy requirements—would offset the cost of the new line. This is further evidence that the CPUC's current oversight of proposed transmission projects lacks the minimum level of diligence necessary to safeguard the economic welfare of consumers.

[51] From the CPUC's November 20, 2009 D.09-11-007, Page 25.

5.4 Renewable Generator Interconnection: Can Renewable Resource Development Move Forward Without Major Network Upgrades?

To understand the implications of the CAISO's various non-economically based approval mechanisms, it is necessary to review, in some detail, those portions of the CAISO's existing tariff dealing with transmission infrastructure.

The CAISO tariff establishes procedures for studying and approving transmission upgrades proposed for "reliability" reasons, "economic" reasons and in connection with the interconnection of new generation. With regard to the interconnection of new generation, the CAISO tariff distinguishes between generator-financed and owned gen-ties, generator-financed and utility-owned Interconnection Facilities, generator-financed and utility-owned Reliability Network Upgrades, and generator-financed and utility-owned Delivery Network Upgrades. The CAISO tariff also provides, in certain circumstances, for a utility-financed and owned radial gen-tie or "trunk line." These trunk-lines are approved under tariff provisions governing Locationally Constrained Resource Interconnection Facilities (LCRIF).

Gen-ties and trunk lines (LCRIF) are radial lines that connect new generation to the network. Interconnection Facilities are substation upgrades that are needed to allow an interconnecting generator to operate at full capacity. Reliability Network Upgrades are additions to the transmission network that are needed to allow an interconnecting generator to operate at full capacity assuming that all other generation in the area can be turned off (which is possible under the CAISO's market-based open access provisions which can impose a very high cost for dispatch when transmission constraints are binding).

The focus of this paper is on network upgrades, specifically the network upgrades that are comparable to, and include, Delivery Network Upgrades in the CAISO's generator interconnection process since they are by far more extensive and costly than other transmission upgrades. These network upgrades are in parallel with existing grid facilities and are discretionary in the sense that their absence would not mean that generation could not be reliably delivered to load, i.e., there would be alternative ways of reliably serving load in the event of critical contingencies. For example, in the absence of the network upgrade, fossil-fired generator redispatch, generator dropping, line-

sectionalization,[52] and/or controlled load drop could be used to ensure generation continues to be reliably delivered to load under contingency conditions.[53]

While no doubt there are exceptions, it is generally the case that the need for gen-ties, trunk lines, Interconnection Facilities, and Reliability Network Upgrades is easily discerned and the alternatives for meeting these needs quite limited. Compared to Delivery Network Upgrades, the magnitude of investment for these facilities tends to be modest.

Delivery Network Upgrades are different. In the absence of a Delivery Network Upgrade, the interconnecting generator could still operate. There could be cost consequences of course, but that is exactly the point. The decision to approve a proposed Delivery Network Upgrade comes down to an economic determination: Is it more economical to build the Delivery Network Upgrade and avoid the cost consequences that could otherwise arise, or is it better to incur the cost consequences and avoid the expense of building the Delivery Network Upgrade?

The reality is that with the possible exception of Reliability Network Upgrades, no proposed network upgrade is *required*. In every imaginable case, there are viable alternatives, wires and/or non-wires (including, in certain circumstances, "no project" alternatives such as new operating procedures) that can and should be evaluated from an economic perspective to confirm that the proposed project is the superior course of action.

5.4.1 Delivery Network Upgrade Study Process

5.4.1.a Are the Delivery Network Upgrade Options Appropriate?

In contrast with radial gen-ties (owned by the generator) and radial trunk-lines (owned by the utility), Delivery Network Upgrades function in parallel with the existing transmission grid and constitute, by far, the largest component of transmission investment identified in the CAISO's generation interconnection studies. As pointed out above, Delivery Network Upgrades are approved by CAISO management without any economic evaluation against viable alternatives. All that is known with certainty is that the Delivery Network Upgrade mitigates at least one reliability criteria violation that occurs under an unusual set of system conditions. What is not known is whether the Delivery

[52] In certain circumstances it is possible to cross-trip a second transmission line and avoid overloads that would otherwise occur for a given contingency. Such cross-tripping can be done without dropping load and may be preferable to other mitigation, such as pre-contingency redispatch of generation.

[53] NERC and WECC reliability criteria permit the use of controlled load drop to mitigate reliability criteria violations that would otherwise occur for N-2 contingencies. Controlled load drop is widely employed throughout the WECC and is accepted practice for maintaining the reliability of the interconnected grid.

Network Upgrade—which will be financed by interconnecting generators and paid for by consumers—is likely to provide life-cycle economic benefits (relative to other viable alternatives) that will exceed the estimated cost of the Delivery Network Upgrade. There is no effective regulatory oversight by the CAISO.

The CAISO's existing interconnection rules require an interconnecting generator to choose either a "Full Capacity" or "Energy Only" status before the interconnection study is performed. Most interconnecting generators are convinced that if they fund the Delivery Network Upgrades identified in connection with selecting "Full Capacity" status, the interconnecting generators can count their capacity towards a CAISO load serving entity's Resource Adequacy (RA) requirements (i.e., will have "capacity value"). And most interconnecting generators believe that if they select "Energy Only" status—wherein possible Delivery Network Upgrades are not even studied—their capacity cannot be counted towards a CAISO load serving entity's Resource Adequacy (RA) requirements (i.e., will not have "capacity value").

Neither belief is accurate. Since the system conditions upon which a Delivery Network Upgrade is identified will inevitably be different when the interconnecting generator comes on line, a generator electing "Full Capacity" status in its interconnection study may not be eligible to be counted towards a CAISO load serving entity's RA requirements. Similarly, a generator electing "Energy Only" status may find that when it comes on line, system conditions would in fact permit the generator's capacity to be counted towards a CAISO load serving entity's RA requirements.

Predictably, most interconnecting generators select "Full Capacity" status and are then confronted with the decision of whether to fund the identified Delivery Network Upgrades. If the interconnecting generator is able to fund the identified Delivery Network Upgrade it will do so because (i) once on line, the generator will be refunded the money, and (ii) most network upgrades will enhance the market value of the interconnecting generator. In this situation the interconnecting generator has little incentive to investigate whether the identified Delivery Network Upgrade was the most economically sensible way of mitigating the reliability criteria violation found in the interconnection study.

On the other hand, if the interconnecting generator finds that the identified Delivery Network Upgrade is so costly that it is unable to fund the upgrade, it can either withdraw its interconnection request—in which case it must reenter at the bottom of the interconnection queue—or switch to "Energy Only" status—in which case no Delivery Network Upgrade will get built. (An interconnecting generator selecting the "Energy Only" option would have no choice of funding a Delivery Network Upgrade since, under current interconnection study rules, the CAISO does not identify Delivery Network

Upgrades for these interconnecting generators.) Therefore, the interconnecting generators in the CAISO balancing authority do not have the practical ability to decide which option is best for them.

5.4.1.b Are the Interconnection Study Assumptions for the "Full Capacity" Option Appropriate? The CAISO's existing generator interconnection process requires that, when identifying Delivery Network Upgrades for interconnecting generators selecting "Full Capacity" status, existing generators have priority over new generators regardless of whether the existing generators are less efficient than the interconnecting generator. This means that, regardless of efficiency, 1) all existing generation in the interconnection study area, both fossil and renewable, will be simultaneously operating at close to full output (although wind is modeled at 40% of nameplate), 2) imports into the CAISO control area are modeled at historically high levels, and 3) all higher-queued generators in the interconnection study area are assumed to actually get built and are modeled at close to full output (although wind is modeled at 40% of nameplate). Once these base case conditions are established, the interconnecting generation under study is ramped up, corresponding adjustments to other generation (or load) are made to maintain a generation-load balance, and contingencies taken to identify any reliability criteria violations.

The interconnection study methodology allows the modeler complete discretion in terms of which generators are backed-down to maintain the generation-load balance. Typically generation is backed-down far from the interconnecting generation location. These back-down decisions are arbitrary and can have significant impacts on network power flows and therefore study results. Some modelers have gone so far as to balance the increased generation by increasing loads,[54] notwithstanding the fact that except for a few water pumping facilities, there is virtually no upwardly dispatchable load anywhere in the WECC.

Given these modeling assumptions, pre-contingency power flows in the area of the interconnecting generator are at high levels. When the output of the interconnecting generator is ramped up under the described conditions, reliability criteria violations are almost certain to be found and Delivery Network Upgrades that mitigate these violations, are almost always identified. In short, the study assumptions exaggerate the level of flows that will actually exist when new generation is added to the grid and have the effect of creating reliability criteria violations that are unlikely to ever materialize, and result in the identification of infrastructure upgrades that will not be needed

[54] As described by an El Paso Electric Company engineer to an interconnecting renewable generator representative.

Alternatives for mitigating the reliability criteria violations may be considered but the utilities (who do most of the interconnection study work) and the CAISO (who is the party responsible for the interconnection studies) will invariably choose the transmission infrastructure addition over other alternatives; especially low cost operational mitigation measures, such as generation tripping and/or controlled load drop that require little, if any, capital expenditures.

These studies are referred to as "deliverability studies;" the theory being that the CAISO can "count on" the capacity from these generators during critical system conditions and that therefore the capacity from these resources can be counted for Resource Adequacy purposes.[55]

Neither the CAISO nor the utilities performing the interconnection studies conducts any formal economic analysis of alternatives to the identified Delivery Network Upgrades. As noted above, the FERC did not accept the CAISO's last attempt to include an economic evaluation methodology in its tariff and, unless other regulatory bodies with approval authorities (such as the California Public Utilities Commission) insist on an economic evaluation, there is no way to know whether the identified Delivery Network Upgrades are in fact the most sensible way to mitigate identified reliability criteria violations.

Finally, the requirement that all existing and higher-queued generation in the interconnection study area be modeled at or near full output *regardless of efficiency* discriminates against efficient new generation. This discriminatory treatment—regrettably sanctioned by the FERC—has contributed to the identification of large and costly Delivery Network Upgrades for which no economic justification is required.

5.4.2 Absent Major Network Upgrades, Will Existing Grid Uses Preclude the Development of New Renewable Resources?

It is an indisputable fact that the existing patterns of grid use will not be the same after the addition of thousands of megawatts of renewable resources with very low variable operating costs. Even accounting for load growth, the amount of low variable cost energy produced by renewable resources will necessarily require substantial reductions in the output of much higher variable cost fossil-fired generation inside and outside California. Because the entire WECC is economically linked through centralized and bilateral markets, it is a certainty that one effect of adding large amounts of renewable resources in southern California—or anywhere else in the WECC for that matter—will be to reduce fossil-fired generation throughout the entire WECC. This

[55] The question of whether it makes sense to impose a deliverability requirement in addition to minimum planning reserves is outside the scope of this paper but is worth thinking about.

would reduce flow on the existing transmission lines both inside and outside California, increasing the amount of transfer capability available to support new renewable generation.

Historically, California has relied heavily on imports to meet load. According to the CAISO's August 25, 2008 report, "California imports approximately 20% of the electrical energy consumed in the state."[56] Increasing renewable generation inside the state and reducing the output of fossil fired generation outside the state will reduce imports into the state, actually unloading the existing interties that have historically delivered much of this power. This reduction in imports will be significant because much of California's renewable resource development potential exists along the major import paths into the state of California. (Since generation developers must absorb the costs of gen-ties, they have an incentive to minimize those costs by locating their resources close to existing bulk power transmission infrastructure.)

Interestingly, the California Transmission Planning Group's (CTPG's) January 13, 2010 Draft Phase 1 Study Report describes a set of analyses—called "Case C"—that were "intended to evaluate existing grid capability, plus those transmission additions included in the WECC 2019 Heavy Summer seed case, to accommodate increased levels of renewable generation development."[57] This analysis suggests that by year 2020, California could meet 32.2% (Table 38) of its forecast retail load with renewable energy sources without adding any new network infrastructure upgrades beyond those included in the WECC's 2019 "Heavy Summer" power flow case.

According to the Case C studies, California's goal of serving 33% of its retail energy demand with renewable resources by year 2020 is well within reach and does not appear to require the vast infrastructure upgrades contemplated by other recent transmission planning studies.[58] The CTPG report provides strong evidence that the existing system can accommodate substantial amounts of new renewable energy development without need for extensive expansion of the grid.

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[56] CAISO's response to: "Experiences w/Joint Transmission Project Development in the West." August 25, 2008

[57] *www.ctpg.us/public/images/stories/downloads/2010_phase_1_ctpg_2020_study_report_011310.pdf*

[58] CTPG's studies do include the transmission additions included in the WECC's 2019 "Heavy Summer" power flow case, so it is not the case that Case C actually tested the capability of only the *existing* grid. (These additions are listed on Table7 of the CTPG report.) It would be interesting to see the results if the transmission additions included in the WECC's 2019 "Heavy Summer" power flow case were removed from the Case C analysis. In any event, the Case C results are in striking contrast to the apparent implications of the other transmission planning studies referenced in this paper.

5.4.3 How Do Proposed Changes to the Transmission Planning Process Affect Renewable Transmission Projects?

The CAISO's proposed RETPP attempts to distinguish between transmission projects that are proposed based on "reliability" and transmission projects that are proposed based on "economics." The trouble with these approval criteria is that they rest upon the unsupportable assumption that different transmission elements serve distinctly different functions and that these functions are sufficient in-and-of-themselves to justify CAISO approval; e.g., that a proposed transmission line identified on the basis of load growth is *required* for "reliability," that a proposed transmission line identified to facilitate renewable resource development is *required* to meet "renewable" resource goals, and that a proposed Delivery Network Upgrade included in a signed LGIA is *required* to interconnect the new generator.

But insofar as these proposed transmission projects are network facilities (i.e., are not radial gen-ties connecting generation or load to the grid), there is no difference in their function. All network transmission provides exactly the same function: it permits the movement of power from generation to load, nothing more, and nothing less. Categorizing transmission projects as "reliability," "economic," "renewable," or "Delivery Network Upgrades" are distinctions without meaning and are not a useful basis for approving proposed transmission projects.

WestConnect's November 23, 2009 response to the FERC's October 8, 2009 "Notice of Request for Comments on Transmission Planning Processes under Order 890" succinctly summarizes the situation:

> **"…**situations in which proposed projects could be deemed necessary based solely on reliability are limited. Economic considerations, e.g. comparison of lower cost wires- and/or non-wires alternatives that would meet applicable reliability standards, are relevant in nearly all cases. A bright line can rarely be drawn between a proposed transmission project deemed necessary based solely on reliability and a proposed project that is chosen based on both reliability and economic considerations." (page 19)

Virtually, all transmission projects provide both reliability and economic benefits to the system. What is different is that different projects provide different levels of benefits (relative to some benchmark) and have different costs. This is true for both wires and non-wires alternatives (including "no project" alternatives where applicable). As will be argued later, this means a reasonable range of practical wires and non-wires alternatives should be evaluated from an economic and environmental perspective before

deciding on the preferred course of action. In almost all cases the only useful question to be answered is an economic one: What is the most economical way to meet the identified need?

It might be tempting to argue that a "reliability" project mitigates an identified reliability criteria violation and that an "economic" project increases transfer capability across an otherwise constrained interface. But this is saying the same thing. A constrained interface is *constrained* to the amount of power that can flow across the interface without violating applicable reliability criteria. The addition of the "economic" project increases the amount of power that can flow, but only up to the level at which the next reliability criteria violation occurs. The "reliability" project mitigates an identified reliability criteria violation and in so doing increases the amount of power that can flow up to the point at which the next reliability criteria violation occurs, exactly the same result as the "economic" project. There is no functional difference.

5.5 Are the modeling assumptions used to determine grid needs, skewed toward transmission expansion?

It is certainly true that new renewable generation will be built. Some of this generation will be located in areas that are not close to the existing bulk power transmission system. This means some, generally radial, transmission facilities will have to be built to get power from the generator bus bar to the existing bulk power grid.

5.5.1 How Is the Capability of the Existing Transmission System Taken into Account in Studies Aimed at Developing Transmission Plans for New Renewable Generation?

Assuming that the radial transmission facilities necessary to connect new renewable generation to the existing bulk power grid will get built, what is the basis for asserting that upgrades of the existing bulk power grid are also needed? The RETI Phase 2A report states flatly that in determining what elements were to be included in the conceptual transmission plan, RETI did not "determine [the] ability of [the] existing system to accommodate flows of new renewable generation." (Page 1-20) Why RETI did not make such determinations is unexplained.

Effectively the same assumption was made in the WGA WREZ initiative. The transmission expansion model developed in connection with the WGA WREZ initiative

was intentionally designed without the capability to simulate how the existing transmission grid would support the development of new renewable resources.[59]

5.5.2 Do Existing Commitments Consume All Existing Transmission Capacity?

The common view is that the existing bulk power network is "full" such that new generation will require upgrades of the network. But where is the evidence? A comprehensive state-wide assessment of existing grid uses has never been assembled. The CAISO produces an aggregate assessment of the amount of import capability into its control area that is available for the import of capacity that counts towards CAISO load serving entities' Resource Adequacy (RA) requirements,[60] but California's municipal utilities have never presented a corresponding assessment of the amount of import capability available on their transmission facilities. And, other than import paths, the CAISO has never attempted to define the extent to which its internal transmission network may be encumbered by existing RA commitments.

Second, the CAISO's RA commitments—which are six-month-ahead paper counting exercises—do not prevent renewable resources from connecting to the grid and

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[59] According to a July 24, 2008 presentation prepared by the Energy Analysis Department of the Berkeley Lab for the WGA WREZ initiative's Generation and Transmission Modeling Work Group, E3's 2008 green house gas calculator model employs renewable energy supply curves that assume, for renewables located outside of California that "new lines must be built to import any new resources." (slide 15) The same presentation describes the development of a Renewable Energy Zones (REZ) analysis tool for the WGA WREZ initiative. The REZ analysis tool was developed to estimate the delivered cost of power, including transmission costs, from each resource type within each WREZ to loads specified by the model user. The presentation states that a "primary assumption" for designing this tool is that there is "no existing transfer capability," i.e., that every new renewable resource will require new network transmission additions. (slide 33)

[60] The CAISO's September 15, 2009 report entitled "2020 Renewable Transmission Conceptual Plan Based on Inputs from the RETI Process, Study Results" shows that the CAISO assumes existing commitments/contracts stay the same even after modeling several thousands of megawatts of new renewable generation. For year 2010 (see *http://www.caiso.com/23dd/23ddde8034350.pdf)* the difference between the maximum import capability (16,777 MW) and the capacity of existing firm pre-RA resources and existing transmission contracts (3,349 MW for loads outside the ISO control area and 8,899 MW for loads inside the ISO control area) defines the ISO's uncommitted import capacity (4,530 MW). Of this, approximately 1,700 MW is available on the ties between northern California and adjacent control areas and 2,830 MW is available on the ties between southern California and adjacent control areas. (See: *http://www.caiso.com/23e6/23e674df52dd0.pdf.)* Based on the data for year 2010, it is assumed that the CAISO control area will have net imports at summer peak of about 11,000 MW. Without any increases in transfer capability between the ISO and adjacent out of state control areas, it is estimated that by year 2020 the internal load serving entities can import about 5,500 MW of new renewable RA capacity. This RA capacity will fill in the uncommitted RA import capability described above.

delivering energy.[61] Under the CAISO's market-based open access paradigm, there is no such thing as a transmission "reservation;" all market participants are permitted to use the grid at any time provided they are willing to accept the economic consequences of such use. The CAISO tariff does not include express provisions that allow the CAISO to "reserve" transmission for anything, including real-time operations and planning purposes. The CAISO would probably argue that its tariff does not *preclude* it from "reserving" transmission for RA purposes. This premise has never been questioned. With respect to interconnecting new renewable generation, the FERC does not permit the CAISO or jurisdictional utilities to refuse interconnection provided the generator funds identified Reliability Network Upgrades, Interconnection Facilities and gen-ties.

Third, if there are existing commitments that are tying up the grid, there is little public information available on the nature of those commitments. For example, the CAISO's import RA assessment provides no detail as to the terms and conditions of the purchase power contracts and out-of-area generation ownership arrangements that underlie the tabulation of how much of the CAISO's existing import capability is available for the import of additional RA capacity. If there are other bases for asserting that the existing bulk power grid is fully utilized (because the CAISO wants to provide a transfer capability cushion in the *event* certain retired generators are returned to service (the Mohave coal plant for example), or to provide transfer capability for generation in the CAISO's interconnection queue that *might* get built, or in *anticipation* of flow limits on downstream transmission paths, or to provide room for *potential* firm imports from outside the state, or to create a *margin* such that the simultaneous feasibility of allocated long-term Congestion Revenue Rights will never be jeopardized) they are not being advertised. And, as noted above, the municipal utilities have never presented a comprehensive assessment of their existing transmission commitments.

Fourth, and perhaps most importantly, there is no indication of the duration of these grid commitments. It is reasonable to expect that over time existing commitments that allow CAISO load serving entities to rely on capacity imports from outside the state—especially from fossil-fired generators—will expire and be replaced with capacity provided by renewable resources inside of California. Logically, municipal utilities will be in a similar situation. Existing contractual commitments for power from fossil-fired generation outside the state will expire on their own terms and load serving entities will replace these commitments with purchases from renewable generation inside the state.

[61] FERC's generator interconnection rules ensure that any generator able to finance the costs of a minimum set of transmission additions (namely, gen-ties, Interconnection Facilities, and Reliability Network Upgrades) can connect and deliver its power to the grid.

The expiration of existing grid commitments will not take place over-night, but it is not reasonable to assume that the existing commitments will continue indefinitely into the future considering the large amounts of renewable generation and distributed generation (such as rooftop solar photovoltaic) that is expected to be added. Only after a full accounting of these commitments is provided can reasonable judgments be made as to the extent to which these commitments will prevent renewable resources from using existing grid transfer capability.

5.5.3 How Are the Generation Dispatch Patterns Selected?

It is not clear how widespread this practice is but there exists considerable leeway in picking and setting the underlying input assumptions in transmission planning base cases used to identify reliability criteria violations and network transmission upgrades that mitigate those violations. A careful review of the CTPG report, for example, reveals that many of the larger upgrades were only identified in select cases by significantly changing the pattern of generation dispatch provided in the WECC 2019 "Heavy Summer" seed case such that, prior to the addition of any new renewable resources, south to north flows on Path 15 were already at the path limit. With this starting point, the CTPG then added renewable generation in southern California and decremented fossil-fired generation in northern California to make room for the renewable generation. Naturally, south to north flows on Path 15 significantly exceeded the path rating and contingency-based reliability criteria violations were inevitable.

These results might be interesting if the CTPG report had provided some rational basis for (i) modifying the dispatch assumptions in the seed case, and (ii) assuming that with this starting point assumption the addition of renewable generation in southern California would result in a reduction in fossil-fired generation in northern California.[62] Without justification, these modifications look like an attempt to create a problem that identified upgrades would solve. In a further assault on credibility, nowhere in the CTPG report are these upgrades evaluated against other measures, such as generation re-dispatch, generator tripping, and/or controlled load-drop, that might also be effective in mitigating the contingency-based reliability criteria violations at comparatively low cost.

[62] Note that historical flows on Path 15 have been largely north to south although there has been a recent trend towards more south to north flows. In order to simulate south to north Path 15 flows at the path limit prior to the addition of any new renewable resources, it is necessary to reduce fossil-fired generation in northern California and increase fossil-fired generation in southern California. With northern California fossil-fired generation already at low levels and fossil-fired generation in southern California already at high levels, one would expect the addition of new renewable resources in southern California to be accommodated mainly by decreases in southern California fossil-fired generation, not decreases in northern California fossil-fired generation. The net result would be a decrease in the level of south to north flows on Path 15, not an increase.

5.6. Are Existing Reliability Criteria Used in California Unreasonably Rigid?

5.6.1 What is "Reliability" and How is it Measured?

It is inarguable that although higher transmission margins should, in theory, lower the risk of brown-outs or black-outs, it is statistically impossible to eliminate the possibility altogether. Bad things canalways happen no matter how much money and infrastructure is brought to bear and mindless pursuit of greater reliability margins is ultimately an exercise in waste. Inevitably, hard judgments must be made as to how much reliability margin is enough.

Federal regulations require that the transmission grid be planned and operated in accordance with reliability criteria developed by the NERC and the WECC. These criteria generally specify that the grid must be capable of accommodating the outage of any one element of the grid (N-1) without loss of load and the loss of two common elements (N-2) (e.g., two circuits on the same set of towers) without uncontrolled load loss. Local balancing authorities may impose stricter criteria and the CAISO has done so by implementing the requirement that the CAISO grid must also be capable of accommodating the outage of one generator followed by the outage of a transmission element (G-1/N-1) without loss of load. This criterion establishes the amount of generating capacity that the CAISO requires load serving entities in the San Diego area to place under contract (local capacity requirements) in order to mitigate the ability of local generators to exercise undue local market power. These contracts impose costs on San Diego area consumers because the import constraints that result from the application of the G-1/N-1 reliability criteria limits competition among the local generators and therefore the incentive to negotiate lower contract prices.

What is not specifically described in these reliability criteria are the system conditions under which the applicable contingencies are to be applied. Typically, utilities and balancing authorities assume stressed system conditions such as one-year-in-ten peak load conditions. As mitigation measures, these standards permit the use of pre-contingency generation redispatch, generator dropping and, for some less likely contingency conditions (N-2 outages), controlled load drop. These operating procedures add little or no ratebase and are usually the last mitigation options to be considered by IOUs, if they are considered at all. From the CAISO's perspective operating procedures are a desirable backstop to new transmission, but are not substitutes for the reliability margin that new infrastructure provides.

5.6.2 How Probable Are Identified Reliability Criteria Violations?

While not specifically prescribed by any criteria, common practice is to apply these reliability criteria for system conditions that are believed to be "stressed." For planning purposes the CAISO typically applies its reliability criteria to system conditions that assume peak loads are at one-year-in-ten levels, i.e., a peak load that has a 10% probability of being exceeded in any year. The logic for using one-year-in-ten load levels in planning studies is that mitigation for reliability criteria violations at this load level will provide a reliability margin for more probable system load conditions.

Whether the resulting probabilities are sensible, however, has never been seriously questioned. It is instructive to perform some simple calculations to get a sense of how likely these events actually are. Roughly speaking, any single transmission element has a forced outage rate of about 1%. A generator on average may have a forced outage rate on the order of 5%. The probability of an overlapping G-1/N-1 event occurring in any hour of the year is therefore about 5% x 1% or 0.05% (0.01 x 0.05 = 0.0005). On an expected basis this amounts to a little over 4 hours per year (8760 x .0005).

The CAISO, however, applies this over-lapping contingency to a peak load condition that is not "expected;" i.e., a peak load that, on a probabilistic basis would only be exceeded one year out of ten. Applying the over-lapping contingency to a peak load condition that has a one-year-in-ten probability of occurrence, the overall probability of the simulated condition is reduced further. To keep the calculations simple, assume that contingency-based system constraints are reached in 200 peak load hours (20 hot days with 10 high load hours each day) in any given one-in-ten-year heat wave. The probability of encountering a load level at which contingency-based system constraints are reached would then be 0.228% (.1 x 200/8760) = .00228

The combined probability of a G-1/N-1 overlapping outage occurring during any one of these peak hours would be .0005 x .00228 = .000001 or about 0.0001% in any given year. This is equivalent to about 30 seconds in a year or 5 minutes in a ten year period. The CAISO's G-1/N-1 reliability criteria, which establishes the local capacity requirements for certain load pockets—such as the San Diego area and, when the Sunrise Powerlink goes in service, the Greater Imperial Valley-San Diego area—is being applied for conditions which, for all practical purposes, will never happen. Yet, hundreds of millions of dollars have been, and likely will be, spent to mitigate the ability of generators within these areas to exercise market power and/or to reduce the amount of local capacity requirements that this improbable study condition indicates.

Adding the effect of using conservatively-rated transmission lines; e.g., using ambient air temperatures that significantly *exceed* the air temperature that would exist

during a one-year-in-ten peak load condition; shrinks the likelihood of actually encountering these limiting conditions even further.

How much are consumers willing to pay to protect against an unlikely event? To answer this it is necessary to estimate both the probability and the consequences of these events. While probabilistic approaches to reliability have been around for many years, they are currently not been used. Under the current deterministic approach to contingency analysis, every conceivable N-1 overload must be mitigated regardless of its probability, consequence, and cost. If probabilistic contingency analysis were adopted, proponents of new transmission infrastructure would need to provide, not only the contingency condition that creates the overload, but also an estimate of the probability with which the contingency will occur and an assessment of what the consequences of the contingency condition will be to electric grid users. With this information, an informed decision could be made as to whether the costs of the proposed project, or the costs of any feasible alternatives, would be offset by the consequences of the overload given its likelihood of occurrence.

Appendices

APPENDIX A

RETI PHASE 2A FINAL REPORT

Posted: September 23, 2009.

Proposed Lines

Table 1-1. Transmission Groups Sorted by Energy, Environmental Rating and Cost.

Foundation & Delivery Lines

	Group Combined CREZ Energy (GWh)	Group Enviro Score	Group Cost ($Million)
Foundation	82,739	1,700	$5,144
Delivery	8,767	739	$788

Collector Lines

Group	Group Combined CREZ Energy (GWh)	Group	Group Enviro Score	Group	Group Cost ($Million)
Imperial	22,377	Carrizo	20	Carrizo	$78
Tehachapi	18,167	Tehachapi	77	LEAPS	$162
IronMt	7,282	BarrenRidge	77	BarrenRidge	$208
MtPass	6,939	Inyo	88	Tehachapi	$531
NorthEast	4,849	Riverside	123	Riverside	$608
BarrenRidge	4,738	IronMt	131	Inyo	$656
Riverside	4,687	LEAPS	246	NorthEast	$735
LEAPS	4,472	MtPass	252	MtPass	$798
Inyo	4,217	North	401	IronMt	$832
North	3,295	NorthEast	600	Imperial	$1,311
Carrizo	2,491	Imperial	837	North	$3,898
Median	**4,738**	**Median**	**131**	**Median**	**$656**

Foundation lines, Renewable Delivery lines and Renewable Collector lines are shown on the map in Figure 1-2.

Appendix H. Line Segment Data

Segment ID#	Line Segment Short Name	Length (Miles)	Cost ($Million)	On-line Date	Enviro Score
1	ALPH4_ALPH1_1	22	34.38	2014	80
2	ALPH4_ALPH1_2	22	34.38	2014	1
3	ALPH4_PARK_1	11	17.19	2014	80
4	ALPH4_PARK_2	11	17.19	2014	1
5	ANTE_VINC_1	21	16.28	2013	2
6	ANTE_VINC_2	17.6	68.20	2013	2
7	AV58_CHCV_1	17.5	32.81	2014	4
8	BAKR1_BARS1_1	50	193.75	2015	48
9	BANN_AV58_1	61	107.41	2014	36
10	BANN_CHCV_1	56.2	140.22	2014	36
11	BANN_DEVR_1	91.2	296.40	2020	216
12	BANN_ELCN_1	27.5	51.56	2013	16
13	BANN_GEO_1	16	25.00	2013	120
14	BANN_GEO_2	16	25.00	2013	1
15	BARS1_KRAM_1	40	130.00	2015	72
16	BARS1_LUGO_1	51	286.88	2015	108
17	BRNR_HASC_1	60	40.50	2013	72
18	BRNR_HASC_2	60	150.00	2013	3
19	CAST_HASC_2	12	7.50	2013	1
20	CHCV_DVR2_1	35	54.69	2014	72
21	CHCV_DVR2_2	35	54.69	2014	2
22	CHCV_MIRG_1	20	13.50	2013	3
23	CHCV_MIRG_2	20	13.50	2013	3
24	CHNO_MIRA_1	6.7	14.66	2013	8
25	CHNO_MIRA_2	6.7	14.66	2013	1
26	CHNO_MIRA_3	6.7	30.53	2013	1
27	CMPL_ECND_1	37	24.98	2013	2
28	CMPL_ECND_2	37	23.13	2013	2
29	CMPL_TALG_1	10	6.75	2013	1
30	CMPL_TALG_2	10	6.25	2013	1
31	COLL_PITT_1	1	1.56	2020	40
32	COLL_PITT_2	1	1.56	2020	1
33	COLL_TRCY2_1	40	130.00	2020	96
34	CONT_LPIN_1	45	202.50	2015	4
35	DESC_DEVR_1	76	247.00	2013	72
36	DESC_DEVR_2	76	247.00	2020	3
37	DEVR_DVR2_1	0.3	0.98	2014	12

Segment ID#	Line Segment Short Name	Length (Miles)	Cost ($Million)	On-line Date	Enviro Score
38	DEVR_MIRA_1	61	190.63	2015	24
39	DEVR_MIRA_2	61	190.63	2017	3
40	DEVR_VALL_2	40	130.00	2013	48
41	DEVR_VALL_3	40	130.00	2020	12
42	DILL_TRCY2_1	43	139.75	2014	144
43	DIXL_BANN_1	43	51.56	2013	8
44	DVR2_CENT_1	175	308.19	2014	288
45	DVR2_VICT_1	133	279.84	2014	150
46	ELCN_HILN_1	19	35.63	2013	4
47	ELCN_HILN_2	19	35.63	2013	1
48	ELCN_IMPV2_2	18	33.75	2013	4
49	GATE_MBAY_1	70	47.25	2012	12
50	GREG_ALPH4_1	100	312.50	2016	144
51	GREG_ALPH4_2	100	312.50	2016	3
52	GULD_EGLR_1	9.4	3.53	2013	1
53	HASC_RNLD_1	15	10.13	2013	1
54	IMPV_BANN_1	51	165.75	2020	216
55	IMPV_XFMR_2	0.0246	51.25	2011	0
56	IMPV_XFMR_3	0.0246	51.25	2012	0
57	INYK_KRAM_1	66	214.50	2015	72
58	IRMT_SCEJ_1	39	134.06	2015	12
59	IRMT_SCEJ_2	39	134.06	2020	2
60	KRAM_LUGO_1	48	270.00	2015	48
61	KRAM_WHUB_1	40	225.00	2015	80
62	LELK_CMPL_1	31	100.75	2013	240
63	LIVR_DELT_1	17	31.88	2014	144
64	LPIN_INYK_1	53	238.50	2015	12
65	LUCV_LUGO_1	21	65.63	2015	36
66	LUGO_VICT_2	15	48.75	2015	8
67	MESA_VINC_2	36	126.00	2013	6
68	MIDP_DESC_1	35	113.75	2013	48
69	MIDW_CARZ_1	46	31.05	2011	8
70	MIDW_GEO_1	16	25.00	2012	80
71	MIDW_GEO_2	16	25.00	2012	1
72	MIDW_GREG_1	141	440.63	2016	192
73	MIDW_GREG_2	141	440.63	2016	4
74	MIDW_KRAM_1	118	368.75	2015	144
75	MIDW_KRAM_2	118	368.75	2015	4
76	MIDW_WRLW_1	72.8	28.21	2013	36
77	MIRG_DEVR_1	15	10.13	2013	1

Segment ID#	Line Segment Short Name	Length (Miles)	Cost ($Million)	On-line Date	Enviro Score
78	MIRG_DEVR_2	15	10.13	2013	1
79	MTPS1_BAKR1_1	50	193.75	2015	48
80	MTPS1_ELDO_1	32	124.00	2012	48
81	NEO_COLL_1	640	2080.00	2020	180
82	OLND_DILL_1	183	594.75	2014	480
83	PISG_BARS1_1	30	97.50	2015	72
84	PISG_LUCV_1	47	146.88	2015	216
85	PISG_MIRA_1	97	375.63	2014	144
86	PRDE_VINC_2	33.2	16.60	2013	2
87	RIOH_VINC_2	32.1	124.39	2013	16
88	SCEJ_CAMI_1	10	38.75	2015	6
89	SCEJ_PISG_1	84	262.50	2015	108
90	SCEJ_PISG_2	84	262.50	2020	3
91	SELK_NEO_1	270	843.75	2020	120
92	SELK_NEO_2	270	843.75	2020	5
93	TESL_NEWK_1	29	54.38	2014	32
94	TRCY2_ALPH4_1	45	140.63	2014	160
95	TRCY2_ALPH4_2	45	140.63	2016	2
96	TRCY2_LIVR_1	13	24.38	2014	4
97	TRCY2_TRCY_1	1	3.25	2014	8
98	VINC_MIRA_1	75	414.03125	2013	12
99	WHUB_ANTE_1	25.6	16.64	2013	2
100	WHUB_WRLW_1	16.8	54.6	2013	12
101	WRLW_ANTE_1	15.6	50.7	2013	24
102	WRLW_VINC_1	33.2	10.79	2013	2
103	ZETA1_OLND_1	42	136.5	2014	96
104	ZETA1_RDMT_1	1	3.25	2014	24

APPENDIX B

CAISO 2020 RENEWABLE TRANSMISSION CONCEPTUAL PLAN BASED ON INPUTS FROM THE RETI PROCESS

9/15/2009 Study

STUDY RESULTS
Proposed Lines

Transmission	Comments	Generic Cost ($Million)
Antelope-Pardee 230 (500) kV line		$2,400.00
Antelope Substation 500/230 kV with 4 AA Banks Antelope Substation 500/230 kV with 4 AA Banks		
Antelope-Vincent #1 500 kV line		
Tehachapi (THP) Substation 1 500/230 kV (Wind hub) with 2 AA Banks Tehachapi (THP) Substation 1 500/230 kV (Wind hub) with 2 AA Banks		
Antelope-Wind hub 500 kV line		
Windhub-Highwind 220 kV line		
Antelope-Vincent #2 500 kV line		
Tehachapi (THP) Substation 5 500/230 kV (Whirlwind) with 2 AA Banks Tehachapi (THP) Substation 5 500/230 kV (Whirlwind) with 2 AA Banks		
Antelope-Whirlwind 500 kV line		
Whirlwind-Cottonwood 230 kV line Whirlwind-Cottonwood 230 kV line		
Static VAR compensator Static VAR compensator		
Wind hub-Whirlwind 500 kV line		
Vincent-Mira Loma 500 kV line		
Vincent – Rio Hondo 230 kV line #2		
Gould – Eagle Rock 230 kV line		

Chino – Mira Loma 230 kV line #3		
Vincent-Mesa 230 (500) kV line		
Loop Midway-Vincent 500 kV line into THP Sub 5 (Whirlwind)		$30

Transmission	Comments	Generic Cost ($Million)
Pisgah 500 kV Substation w 3 AA banks		$551
El Dorado - Lugo 500 kV loop-in to Pisgah		
Mohave - Lugo 500 kV loop-in to Pisgah		
Pisgah - Rancho Vista 500 kV		

Transmission	Comments	Generic Cost ($Million)
Replace Imperial Valley #1 500/230 kV Bank		$36
Imperial Valley #3 500/230 kV Bank		$36
Sunrise Powerlink 500 kV line		$1,900

Transmission	Comments	Generic Cost ($Million)
Carrizo 230 kV substation		$153
Carrizo - Midway 230 kV #1 and #2		

Transmission	Comments	Generic Cost ($Million)
Contra Costa-Moraga #1 230 kV line		$20
Contra Costa-Moraga #2 230 kV line		$20
Contra Costa-Las Positas 230 kV line		$15
Newark-Ravenswood 230 kV line		$5
Tesla-Pittsburg #1 230 kV line		$15
Tesla-Pittsburg #2 230 kV line		$15
Contra Costa-Delta Pump 230 kV line		$10

Transmission	Comments	Generic Cost ($Million)
Ivanpah 230 kV sub		$145
El Dorado- Ivanpah 230 kV #1 and #2		

Transmission	Comments	Generic Cost ($Million)
Loop Gates-Morro Bay #2 230 kV into Templeton		$140
Reconductor Gates-Templeton #1 and #2 230 kV		
Expand Templeton to BAHH		

Transmission	Comments	Generic Cost ($Million)
New Hatch Ridge 230 kV Substation		$40
Loop Pit 3-Round Mountain into Hatch Ridge		

Transmission	Comments	Generic Cost ($Million)
Reconductor Hatch Ridge-Round Mountain 230 kV		$20
Reconductor Pit 1-Cottonwood 230 kV		$60

Transmission	Comments	Generic Cost ($Million)
Colorado River 500/230 kV Sub w 3 AA banks		$1,251
Red Bluff 500/230 kV Sub w 2 AA banks		
DPV1 loop-in to Colorado River and Red Bluff		
Colorado River – Red Bluff - Devers 2nd 500 kV line		
Red Bluff - Valley 500 kV line		
Devers - Valley 2nd 500 kV		

Transmission	Comments	Generic Cost ($Million)
Devers – El Casco 230 kV #1		$40
El Casco – San Bernardino 230 kV #1		
Devers – San Bernardino 230 kV #1		$40
Devers – Vista 230 kV #1		$40
Devers – Vista 230 kV #1		$40

Transmission	Comments	Generic Cost ($Million)
Kramer 500 kV Substation w/ 3 AA banks		$635
Kramer - Mira Loma 500 kV line		
Kramer - Whirlwind 500 kV line		
Victor-Lugo #3 230 kV line		

Transmission	Comments	Generic Cost ($Million)
Green Path North	LADWP	$500

Transmission	Comments	Generic Cost ($Million)
New Windfarm/ECO 500/230 kV Substation		$270
1 x 500/230 kV and 1x 230/138 kV Banks		
Imperial Valley – Miguel 500 kV line loop-in to ECO substation		

No.	Overloaded Facilities	Rating Amps	Critical Contingencies	Category	Loading	Proposed Solutions	Unit Cost x $Million (2008$)
1	Hatch Ridge-Round Mountain 230 KV	399	Malin - Round Mountain #1 500 kV Line	B	105.1%	Reconductor	$20
			Olinda - Tracy 500kV Line	B	107.5%		
2	Westley-Los Banos 230 KV	1700	Metcalf - Moss Landing 500kV Line	B	100.9%	Reconductor	$50
3	Gates-Midway 230 KV	941	Gates 500/230kV Bk # 11 Transformer	B	104.2%	Reconductor	$70

No.	Overloaded Facilities	Rating Amps (T/L) or MVA (XFMR)	Critical Contingencies	Category	Loading	Proposed Solutions	Unit Cost x $Million (2008$)
1	Antelope 230/66 kV No.1, No.2, and No.4 Transformers	280 MVA	Base Case	A	116%	Energize No.3 bank (spare) and split 230 kV bus.	$5
2	El Casco 230/115 kV No.1 and No.2 Transformers	309 MVA (N-1)	Loss of one El Casco 230/115 kV Transformer	B	127%	Add El Casco 230/115 kV No. 3 Transformer	$8
3	Kramer 230/115 kV No.1 Transformer	250 MVA (N-1)	Loss of Kramer 230/115 kV No. 2 Transformer	B	152%	Add Kramer 230/115 kV No.3 Transformer	$8
4	Mira LomaW 500/230 kV No.1 and No.2 Transformers	1120 MVA (N-1)	Loss of one Mira LomaW 500/230 kV Transformer	B	114%	Add Mira LomaW 500/230 kV No.3 Transformer	$32
5	Serrano 500/230 kV No.1, No.2, and No.3 Transformers	1120 MVA (N-1)	Loss of Serrano 500/230 kV No.1 Transformer	B	124%	Add Serrano 500/230 kV No.4 Transformer	$31
6	Sylmar 230 kV No.1 and No.2 Transformers	600 MVA (N-1)	Loss of Sylmar 230 kV No.3 Transformer	B	127%	LADWP to add Sylmar 230 kV No.4 Transformer	$31
7	Valley 500/115 kV No.3 and No.4 Transformers	672 MVA (N-1)	Loss of Valley 500/115 kV No.3 or No.4 Transformers	B	181%	Add Alberhill 500/115 kV Substation (2 AA Banks)	$85
8	Holgate-Kramer 115 kV T/L	477 Amps (N-1)	Loss of Edwards-Holgate 115 kV T/L	B	101%	Add Holgate-Kramer No.2 115 kV T/L (11 miles)	$21
9	Lugo-Pisgah No.1 and No.2 500 kV T/L	3932 Amps (N-1)	Loss of one Lugo-Pisgah 500 kV T/L	B	104%	Add Kramer-Barstow-Pisgah 500 kV T/L (70 miles)	$228
10	Serrano-Villa Park No.1 and No.2 230 kV T/L	3231 Amps (N-1)	Loss of one Serrano-Villa Park 230 kV T/L	B	103%	Add Serrano-Villa Park No. 230 kV T/L (4 miles)	$8
11	Blythe-Eagle Mountain 161 kV T/L	724 Amps (N-2)	Loss of Eagle Mountain-Iron Mountain 230 kV T/L and Julian Hinds-Mirage 230 kV T/L	C	131%	Add Blythe-Eagle Mountain No.2 161 kV T/L (53 miles)	$99
12	La Cienega-La Fresa 230 kV T/L	1614 Amps (N-2)	Loss of El Nido-La Fresa No.3 and No.4 T/L	C	182%	La Cienega-La Fresa No.2 230 kV T/L (13 miles)	$24
13	Pardee-Moorpark No.2 and No.3 230 kV T/L	2279 Amps (N-2)	Loss of Pardee-Moorpark No.1 230 kV T/L and Pardee-Moorpark No. 3 230 kV T/L	C	109%	Pardee-Moorpark No.4 230 kV T/L (27 miles)	$17
14	Vincent 500/230 kV AA Banks Barre-Lewis 230 kV T/L Barre-Villa Park 230 kV T/L Mira LomaE-Olinda 230 kV T/L Mira LomaW-Walnut 230 kV T/L Mira Loma AW 500/230 kV AA Banks Lewis-Villa Park 230 kV T/L	Various	Various	B and C	Various	Upgrade Mesa to 500 kV substation with 2 AA banks, add Mesa-Vincent No.1 (36 miles) and No.2 (43 miles) 500 kV T/L, add Mesa-Serrano 500 kV T/L (50 miles), upgrade Lighthipe to 500 kV substation with 2 AA banks, Lighthipe-Mesa 500 kV T/L (13 miles)	$663

No.	Overloaded Facilities	Rating Amps (T/L) or MVA (XFMR)	Critical Contingencies	Category	Loading	Proposed Solutions	Unit Cost x $Million (2008$)
1	Holgate-Kramer 115 kV T/L	415 AMPS (N-0)	Base Case	A	107.50%	Add Holgate-Kramer No.2 115 kV T/L (11 miles)	$21
2	Kramer 230/115 kV No.1 Transformer	250 MVA (N-1)	Loss of Kramer 230/115 kV No. 2 Transformer	B	138.90%	Add Kramer 230/115 kV No.3 Transformer	$8
3	Valley 500/115 kV No.3 and No.4 Transformers	672 MVA (N-1)	Loss of Valley 500/115 kV No.3 or No.4 Transformers	B	99.50%	Add Alberhill 500/115 kV Substation (2 AA Banks)	$85
4	Vincent 500/230 kV AA Banks Barre-Lewis 230 kV T/L Barre-Villa Park 230 kV T/L Mira LomaE-Olinda 230 kV T/L Mira LomaW-Walnut 230 kV T/L Mira Loma AW 500/230 kV AA Banks Lewis-Villa Park 230 kV T/L	Various	Various	B and C	Various	Add Mesa-Vincent No.1 (36 miles) and No.2 (43 miles) 500 kV T/L, add Mesa-Serrano 500 kV T/L (50 miles), upgrade Lighthipe to 500 kV substation with 2 AA banks, Lighthipe-Mesa 500 kV T/L (13 miles)	$663

No.	Overloaded Facilities	Rating MVA	Critical Contingencies	Category	Loading	Proposed Solutions	Unit Cost x $Million (2008$)
1	N/A	N/A	Windfarm-Miguel 500 kV w/IV generation SPS and cross-trip of Otay Mesa-Tijuana 230 kV	B	Stability	Imperial Valley-Bannister-Devers 500 kV	$577
			Imperial Valley-Suncrest & Imperial Valley-Windfarm 500 kV	C5	Stability		
			Imperial Valley-Suncrest & Imperial Valley-Windfarm 500 kV, w/IV generation SPS	C5	Stability		
			Imperial Valley-Suncrest & Imperial Valley-Windfarm 500 kV w/IV generation SPS and cross-trip of Otay Mesa-Tijuana 230 kV	C5	Stability		
2	Sycamore-Scripps 69 kV	160	Windfarm-Miguel 500 kV	B	1.103	Sycamore Canyon-Penasquitos 230 kV	$153
			Windfarm-Miguel 500 kV w/IV gentrip SPS (6.1)	B	1.024		
			Imperial Valley-Windfarm 500 kV	B	1.065		
			Imperial Valley-Windfarm 500 kV w/IV gentrip SPS and Otay Mesa-Tijuana 230 kV crosstrip (6.2)	B	1.037		
			Otay Mesa-South Bay 230 kV	B	1.126		
			Penisquitos-Old Town 230 kV	B	1.008		
			Encina Tap 230 kV	B	1.03		
			Palomar-Sycamore Canyon 230 kV	B	1.041		
			Silvergate-South Bay 230 kV	B	1.026		
			Sycamore 230/138 kV Bank	B	1.058		
3	Sycamore-Carlton Hills Tap 138 kV	247	Windfarm-Miguel 500 kV	B	1.182		
			Windfarm-Miguel 500 kV w/IV gentrip SPS (6.1)	B	1.091		
			Imperial Valley-Windfarm 500 kV	B	1.116		
			Imperial Valley-Windfarm 500 kV w/IV gentrip SPS (6.1)	B	1.029		
			Imperial Valley-Windfarm 500 kV w/IV gentrip SPS and Otay Mesa-Tijuana 230 kV crosstrip (6.2)	B	1.119		
4	Sycamore-Creelman 69 kV	90	Windfarm-Miguel 500 kV	B	1.156	Imperial Valley-Bannister-Devers 500 kV and Sycamore Canyon-Penasquitos 230 kV	–
			Windfarm-Miguel 500 kV w/IV gentrip SPS (6.1)	B	1.136		
			Windfarm-Miguel 500 kV w/IV gentrip SPS and Otay Mesa-Tijuana 230 kV crosstrip (6.2)	B	1.207		
			Imperial Valley-Windfarm 500 kV	B	1.189		
			Imperial Valley-Windfarm 500 kV w/IV gentrip SPS (6.1)	B	1.14		
5	Sycamore-Chicarita 138 kV	204	Palomar-Sycamore Canyon & Encina Tap 230 kV	C5	1.139		
			Encina 230 kV Tap	B	1.058		
			Palomar-Sycamore Canyon 230 kV	B	1.119		
			Silvergate-South Bay 230 kV	B	1.02		
			Encina 230/138 kV bank	B	1.232		
			Otay Mesa-South Bay 230 kV	B	1.112		
			Penisquitos-Old Town 230 kV	B	1.018		
6	Poway-Pomerado 69 kV	143	Palomar-Sycamore Canyon 230 kV	B	1.017		
7	Central-Sycamore 230 kV #1	1176	Windfarm-Miguel 500 kV w/IV gentrip SPS and Otay Mesa-	B	1.027	Central-Sycamore 230 kV #3 & #4	$432
8	Central-Sycamore 230 kV #2	1176	Windfarm-Miguel 500 kV w/IV gentrip SPS and Otay Mesa-	B	1.027		
9	Miguel 500/230 kV #1 (ML Bank 80)	1329	Miguel 500/230 kV #1 (ML Bank 81) w/IV gentrip (SPS 6.6f)	B	1.07	Miguel 500/230 kV Bank #3	$97
10	Miguel 500/230 kV #2 (ML Bank 81)	1344	Miguel 500/230 kV #1 (ML Bank 80) w/IV gentrip (SPS 6.6f)	B	1.07		

APPENDIX C

CTPG FINAL PHASE 1 STUDY REPORT
February 17, 2010

Proposed Lines

8 Comparison of CTPG and RETI Phase 2A Conceptual Transmission Plans

Table 48: Comparison of CTPF and RETI Phase 2A Conceptual Transmission Plans - Network Upgrades

Transmission Project	RETI Phase 2A Conceptual Plan	WECC 2019 Seed Case	CASE A	CASE A S-N	CASE A S-N TEWA	CASE B	CASE C	Comments
500 kV Selkirk-Devil's Gap-NEO #1 line	X							
500 kV Selkirk-Devil's Gap-NEO #2 line	X							
+/- 500 kV DC Neo-Collinsville #1 line	X							
230 kV Collinsville-Pittsburg #1 line	X							
230 kV Collinsville-Pittsburg #2 line	X							
500 kV Collinsville-Tracy2 #1 line	X							
500 kV Zeta1-Round Mountain #1 line	X							
500 kV Zeta1-Olinda #1 line	X							
500 kV Olinda-Dillard Road #1 line	X							
230 kV Dillard Road-Tracy2 #1 line	X							
230 kV Tracy2-Livermore #1 line	X							
230 kV Livermore-Delta #1 line	X							
500 kV Tracy2-Tracy #1 line	X							
500 kV Tracy2-Alpha4 #1 line	X							
500 kV Tracy2-Alpha4 #2 line	X							
230 kV Alpha4-Park #1 line	X							
230 kV Alpha4-Park #2 line	X							
230 kV Alpha4-Alpha1 #1 line	X							
230 kV Alpha4-Alpha1 #1 line	X							
230 kV Tesla-Newark #1 line	X							
500 kV Gregg-Alpha4 #2 line	X							
500 kV Tesla-Warnerville #1 line					X			
230 kV Westley-Los Banos #1 reconductor				X	X			
500 kV Gregg-Warnerville #1 line				X	X			
500 kV Gregg-Rancho Seco #1 line				X	X			
500 kV Midway-Gregg #1 line				X	X			

Transmission Project	RETI Phase 2A Conceptual Plan	WECC 2019 Seed Case	CASE A	CASE A S-N	CASE A S-N TEWA	CASE B	CASE C	Comments
500 kV Midway-Gregg #2 line				X	X			
500 kV Midway-Kramer #1 line	X			X	X			
230 kV Gates-Morro Bay #1 upgrade project	X							
230 kV Midway-Carrizo #1 upgrade project	X	X	X	X	X	X	X	
500 kV Midway-Kramer #2 line	X							
500 kV Midway-Whirlwind #1 upgrade project	X	X	X	X	X	X	X	Part of Tehachapi Segments 4-11
500 kV Windhub-Antelope #1 line		X	X	X	X	X	X	Part of Tehachapi Segments 4-11
500 kV Windhub-Whirlwind #1 line	X	X	X	X	X	X	X	Part of Tehachapi Segments 4-11
500 kV Whirlwind-Antelope #1 line	X	X	X	X	X	X	X	Part of Tehachapi Segments 4-11
500 kV Whirlwind-Vincent #1 line	X	X	X	X	X	X	X	Part of Tehachapi Segments 4-11
500 kV Antelope-Vincent #1 replacement project	X	X	X	X	X	X	X	Part of Tehachapi Segments 4-11
500 kV Antelope-Vincent #2 line	X	X	X	X	X	X	X	Part of Tehachapi Segments 4-11
220 kV kV Chino-Mira Loma #1 replacement project	X	X	X	X	X	X	X	Part of Tehachapi Segments 4-11
220 kV Chino-Mira Loma #2 line	X	X	X	X	X	X	X	Part of Tehachapi Segments 4-11
220 kV Chino-Mira Loma #3 line	X	X	X	X	X	X	X	Part of Tehachapi Segments 4-11
220 kV Gould-Eagle Rock #1 line	X	X	X	X	X	X	X	Part of Tehachapi Segments 4-11
500 kV Mesa-Vincent #2 line	X	X	X	X	X	X	X	Part of Tehachapi Segments 4-11
230 kV Pardee-Vincent #2 line	X	X	X	X	X	X	X	Part of Tehachapi Segments 4-11
230 kV Rio Hondo-Vincent #2 line	X	X	X	X	X	X	X	Part of Tehachapi Segments 4-11
500 kV Vincent-Mira Loma #1 replacement project	X	X	X	X	X	X	X	Part of Tehachapi Segments 4-11
500 kV Kramer-Windhub #1 line	X							
230 kV Control-Lone Pine #1 rebuild project	X							Northern portion of 230 kV Control-Inyokern #1 line
230 kV Lone Pine-Inyokern #1 rebuild project	X							Southern portion of 230 kV Control-Inyokern #1 line
230 kV Control-Inyokern #2 line						X		
500 kV Inyokern-Kramer #1 line	X					X		Included as 230 kV Inyokern-Kramer #1 & #2 lines
Reconductor short 230 kV tie between SCE						X	X	Case C identified base case

Transmission Project	RETI Phase 2A Conceptual Plan	WECC 2019 Seed Case	CASE A	CASE A S-N	CASE A S-N TEWA	CASE B	CASE C	Comments
and MWD at Julian Hinds substation								overload at this line. The reconductor of this line can be a mitigation for this overload
500 kV Iron Mountain-Jontry Junction #1 rebuild project	X							
500 kV Iron Mountain-Jontry Junction #2 line	X							
500 kV Jontry Junction-Camino #1 rebuild project	X							
500 kV Jontry Junction-Pisgah #1 line	X							
500 kV Jontry Junction-Pisgah #2 line	X							
500 kV Pisgah-Lucerne Valley #1 line	X							
500 kV Lucerne Valley-Lugo #1 line	X							
New Mountain Pass 287 kV substation loop-in LADWP's existing 287 kV Mead-Victorville #1 line	X		X			X		These network upgrades were assumed for purposes of connecting the Pisgah, Mountain Pass, Baker and Barstow CREZs in CTPG's A2 and B2 cases. CTPG's C2 case used a different connection scheme for these CREZs that did include any new network line segments and did not include the new Mountain Pass 287 kV substation.
500 kV Mountain Pass1-El Dorado #1 replacement project	X		X			X		
500 kV Mountain Pass1-Baker1 #1 replacement project	X		X			X		
500 kV Baker1-Barstow1 #1 replacement project	X		X			X		
500 kV Pisgah-Barstow1 #1 line	X		X			X		
500 kV Barstow1-Kramer #1 line	X		X	X	X	X		
500 kV Barstow1-Lugo #1 line	X		X			X		
500 kV Kramer-Lugo #1 line	X		X	X	X	X		Case C identified a base case overload on the 230 kV Kramer-Lugo #1& #2 lines. It is expected that a 500 kV Kramer-Lugo #1 line would mitigate the overloads but was not tested in the Case C studies.

Transmission Project	RETI Phase 2A Conceptual Plan	WECC 2019 Seed Case	CASE A	CASE A S-N	CASE A S-N TEWA	CASE B	CASE C	Comments
500 kV Lugo-Victorville #2 line	X							
230 kV Barren Ridge-Haskell Canyon #1 upgrade project	X	X	X	X	X	X	X	Included in the 2019 WECC seed case as part of the Barren Ridge upgrade project
230 kV Barren Ridge-Haskell Canyon #2 line	X	X	X	X	X	X	X	
230 kV Castaic-Haskell Canyon #2 line	X	X	X	X	X	X	X	
230 kV Haskell Canyon-Rinaldi #1 upgrade project	X	X	X	X	X	X	X	
500 kV Barren Ridge-Vincent #1 line						X		Changing the assumed connection pattern of renewables in the Tehachapi area may eliminate the criteria violation that this upgrade mitigates.
500 kV Colorado River-Desert Center #2 line[5]	X	X	X	X	X	X	X	Eastern portion of 500 kV Colorado River-Devers #2 line included in 2019 WECC seed case. Cases A, B and C excluded the new Desert Center substation assumed by RETI.
500 kV Desert Center-Devers #2 line[6]	X	X	X	X	X	X	X	Western portion of 500 kV Colorado River-Devers #2 line included in 2019 WECC seed case. Cases A, B and C excluded the Desert Center substation assumed by RETI.
500 kV Desert Center-Devers #3 line	X							
Replacement of existing small 500/230 kV transformer at Imperial Valley substation	X							
Third 500/230 kV transformer at Imperial Valley substation	X							
230 kV El Centro-Imperial Valley #2 line	X							Case C studies suggest (i) a 500

[5] According to the CPUC-approved plan of service, the existing 500 kV Palo Verde-Devers #1 line will be looped into the new Colorado River substation. RETI assumed that a new Desert Center substation would also be looped into the existing 500 kV Palo Verde-Devers #1 line. These loop-ins would create a 500 kV Colorado River-Desert Center #1 and 500 kV Desert Center-Devers #1 lines. CTPG does not assume a Desert Center substation.
[6] See footnote above.

Transmission Project	RETI Phase 2A Conceptual Plan	WECC 2019 Seed Case	CASE A	CASE A S-N	CASE A S-N TEWA	CASE B	CASE C	Comments
230 kV El Centro-Highline #1 upgrade project	X							kV Imperial Valley-Bannister-Devers #1 line, or (ii) 230 kV El Centro-Imperial Valley #2 line + 230 kV El Centro-Highline #1 & #2 lines would be useful in maximizing the dispatch of renewable resources in the Imperial Valley.
230 kV El Centro-Highline #2 line	X							
500 kV Imperial Valley-Bannister #1 line	X							
500 kV Bannister-Devers #1 line	X							
230 kV Dixieland-Bannister #1 rebuild project	X							
230 kV Bannister-El Centro #1 line	X							
230 kV Bannister-Geo #1 line	X							
230 kV Bannister-Geo #2 line	X							
230 kV Midway-Geo #1 line	X	X	X	X	X	X	X	Included in the 2019 WECC seed case
230 kV Midway-Geo #2 line	X	X	X	X	X	X	X	
230 kV Bannister-Coachella Valley #1 line	X							
230 kV Bannister-Avenue58 #1 rebuild project	X							
230 kV Avenue58-Coachella Valley #1 rebuild project	X							
230 kV Coachella Valley-Mirage #1 upgrade project	X							
230 kV Coachella Valley-Mirage #2 upgrade project	X							
230 kV Mirage-Devers #1 upgrade project	X	X	X	X	X	X	X	
230 kV Mirage-Devers #2 upgrade project	X	X	X	X	X	X	X	
230 kV Coachella Valley-Devers2 #1 line	X	X	X	X	X	X	X	Part of 500 kV GPN Project included in 2019 WECC seed case
230 kV Coachella Valley-Devers2 #2 line	X	X	X	X	X	X	X	CTPG labels this as 230 kV Coachella Valley-Indian Hill #2 line
230 kV Devers2-Century #1 line	X							RETI included this as part of the 230 kV version of the Green Path North Project
230 kV Devers2-Victorville #1 line	X							RETI included this as part of the

Transmission Project	RETI Phase 2A Conceptual Plan	WECC 2019 Seed Case	CASE A	CASE A S-N	CASE A S-N TEWA	CASE B	CASE C	Comments
								230 kV version of the Green Path North Project
500 kV Devers-Devers2 #1 line	X	X	X	X	X	X	X	CTPG labels this as 500 kV Devers-Indian Hill #1 line. RETI included this as part of the "230 kV" version of the Green Path North Project
500 kV Devers-Mira Loma #1 line	X							
500 kV Devers-Mira Loma #2 line	X							
500 kV Devers-Valley #2 line	X	X	X	X	X	X	X	Part of Colorado River-Devers #2 project included in 2019 WECC seed case
500 kV Devers-Valley #3 line	X							
500 kV Lee Lake-Camp Pendleton #1 line	X							The 500 kV Talega-Escondido/Valley-Serrano (TE/VS) transmission project was not included.
230 kV Camp Pendleton-Escondido #1 upgrade project	X							
230 kV Camp Pendleton-Escondido #2 line	X							
230 kV Camp Pendleton-Talega #1 upgrade project	X							
230 kV Camp Pendleton-Talega #2 line	X							

APPENDIX D

CALIFORNIA IOUs INDIVIDUAL and TOTAL TRANSMISSION RATE BASE 1998-2009

SDG&E

	Beginning of Year	Additions During the Year	Growth Relative to End of Year 1998	Net Energy for Load (gWh)	Growth Relative to 1999
1999	$691,827,871	$25,444,834	1.00	19259	1.00
2000	$706,590,151	$20,010,778	1.02	20277	1.05
2001	$724,631,543	$44,416,061	1.05	18694	0.97
2002	$765,152,822	$66,832,563	1.11	19001	0.99
2003	$826,297,882	$48,040,915	1.19	19675	1.02
2004	$872,625,580	$85,375,331	1.26	20616	1.07
2005	$954,702,679	$104,653,341	1.38	20575	1.07
2006	$1,061,157,672	$116,199,343	1.53	21567	1.12
2007	$1,176,414,256	$203,686,431	1.70	21703	1.13
2008	$1,373,032,852	$154,140,918	1.98	22085	1.15
2009	$1,527,173,770		2.21	21599	1.12

SCE

Beginning of Year	Additions During the Year	Growth Relative to End of Year 1998	Net Energy for Load (gWh)	Growth Relative to 1999
$2,997,879,277	$148,889,915	1.00	93199	1.00
$3,130,260,019	$167,481,935	1.04	101323	1.09
$3,251,423,789	$108,153,529	1.08	92914	1.00
$3,337,940,779	$145,105,242	1.11	94207	1.01
$3,438,124,857	$168,002,508	1.15	95582	1.03
$3,569,213,690	$255,045,782	1.19	99126	1.06
$3,791,060,500	$305,953,964	1.26	100978	1.08
$4,056,240,015	$355,829,337	1.35	103769	1.11
$4,381,950,467	$307,343,181	1.46	103774	1.11
$4,655,424,552	$125,696,405	1.55	105806	1.14
$4,781,120,957		1.59	101444	1.09

PG&E

Beginning of Year	Additions During the Year	Growth Relative to End of Year 1998	Net Energy for Load (gWh)	Growth Relative to 1999
$2,486,720,423	$158,770,331	1.00	102368	1.00
$2,583,068,880	$116,434,661	1.04	105710	1.03
$2,657,194,014	$140,165,659	1.07	100205	0.98
$2,781,332,124	$186,529,493	1.12	101023	0.99
$2,959,299,313	$493,839,830	1.19	103059	1.01
$3,418,693,642	$304,883,894	1.37	106429	1.04
$3,713,173,312	$267,654,112	1.49	106234	1.04
$3,960,944,547	$530,542,988	1.59	109498	1.07
$4,466,026,176	$316,113,593	1.80	114062	1.11
$4,744,488,146	$318,417,000	1.91	115951	1.13
$5,062,905,146		2.04	112051	1.09

Total California Investor Owned Utilities

Beginning of Year	Growth Relative to End of Year 1998	Net Energy for Load (gWh)	Growth Relative to 1999
$6,176,427,571	1.00	214826	1.00
$6,419,919,050	1.04	227310	1.06
$6,633,249,346	1.07	211812	0.99
$6,884,425,725	1.11	214230	1.00
$7,223,722,052	1.17	218316	1.02
$7,860,532,912	1.27	226171	1.05
$8,458,936,491	1.37	227787	1.06
$9,078,342,234	1.47	234834	1.09
$10,024,390,899	1.62	239540	1.12
$10,772,945,550	1.74	243842	1.14
$11,371,199,873	1.84	235093	1.09

APPENDIX E
Partial List of California Proposed Interties

- Sunzia (central New Mexico – Phoenix/Tucson, Arizona area) 500 kV $800 million
- Gateway West (eastern Wyoming – western Idaho) 230 kV/500 kV
- Gateway South (southeastern Wyoming – southern Nevada) 500 kV
- Southwest Intertie project (southern Idaho – southern Nevada) 500 kV
- Southern Navajo upgrade
- Navajo-Crystal upgrade
- Perkins-Mead upgrade
- Wyoming-Colorado intertie (northeastern Wyoming – central Colorado (Pawnee)) 345 kV $325 million
- High Plains Express (eastern Wyoming – eastern Colorado – New Mexico – Phoenix/Tucson area) 500 kV $5 billion
- Frontier Line (+/- 500 kV DC line connecting southwest Wyoming – Utah – southern Nevada)
- Transwest Express (+/- 600 kV DC line connecting southwest Wyoming – Utah – southern Nevada) $3 billion
- Chinook (+/- 500 kV DC line connecting southern Montana – southern Idaho – southern Nevada) $3 billion
- Zephyr (+/- 500 kV DC line connecting southern Colorado – southern Idaho – southern Nevada) $3 billion
- Delaney-Palo Verde (500 kV AC line) $69 million
- Palo Verde-North Gila #2 (500 kV AC line) $243 million
- Palo Verde-Liberty-Gila Bend (500 kV AC line) $35 million + ($42 million + $35 million)
- Robinson Summit – southern Nevada (eastern Nevada north-south) 500 kV
- Carson City-southern Nevada (western Nevada north-south) 345 kV
- Valmy-Carson City (east-west) 345 kV

APPENDIX F

Maps of Tehachapi and Sunrise Transmission Lines

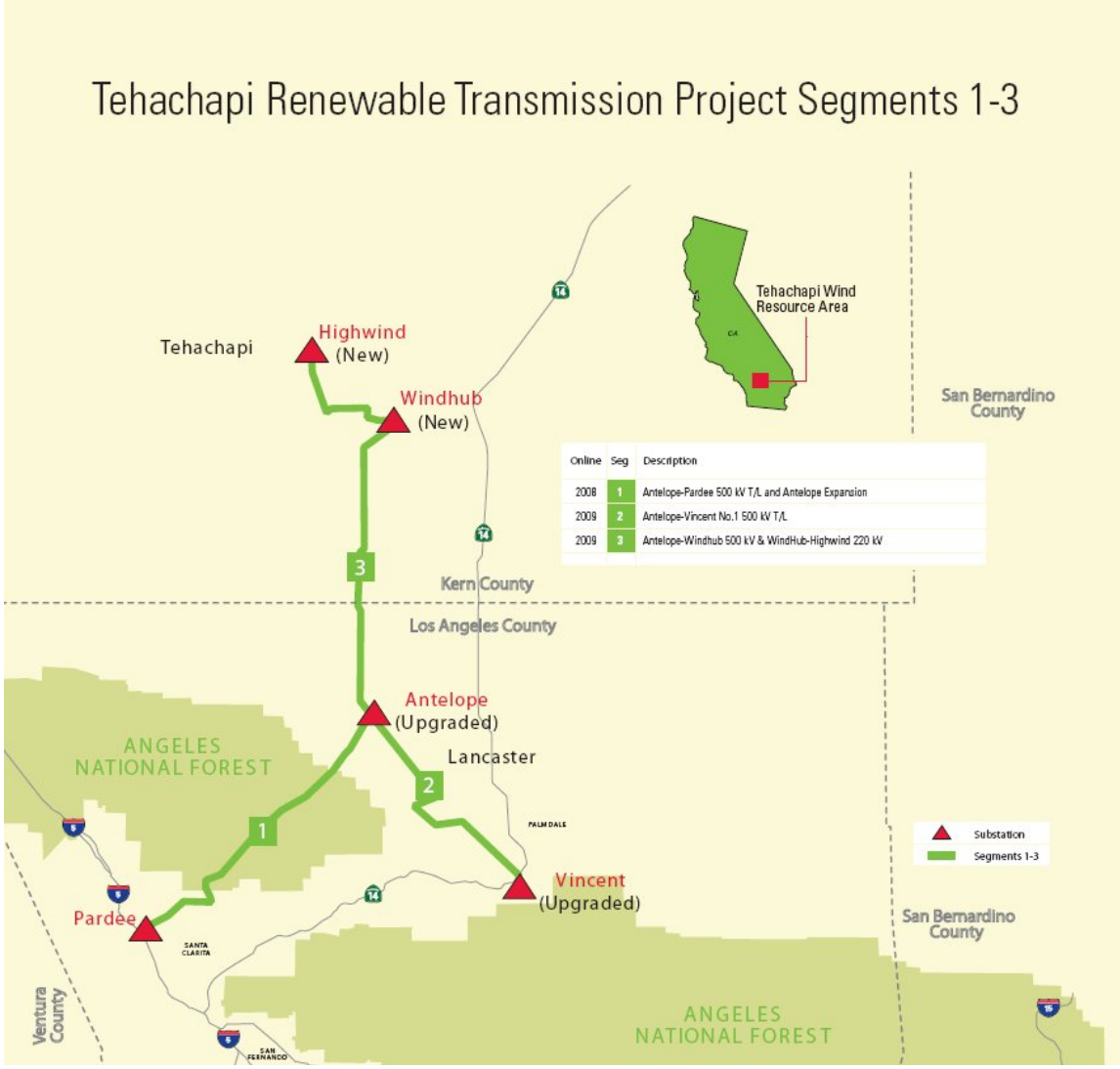
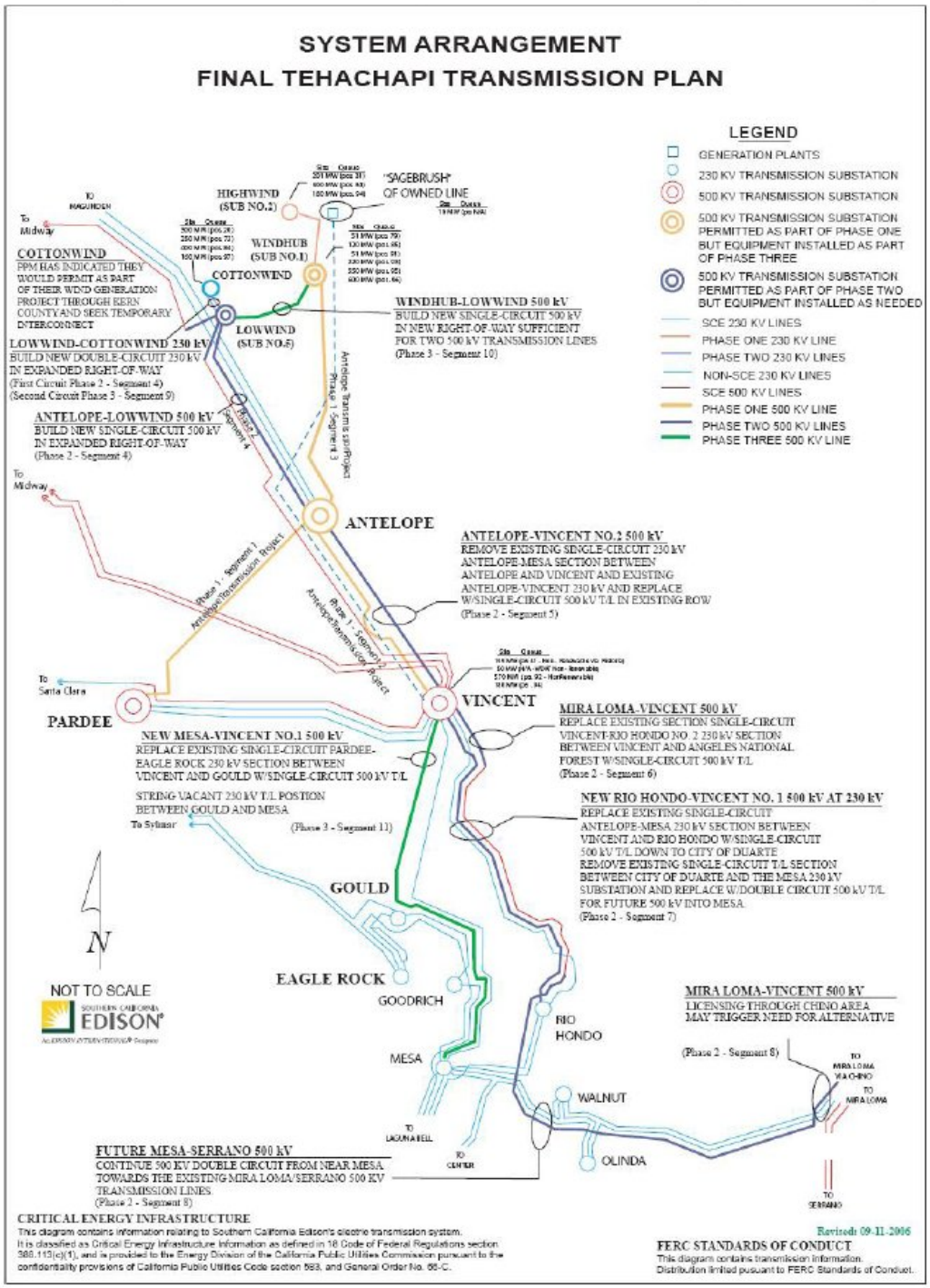
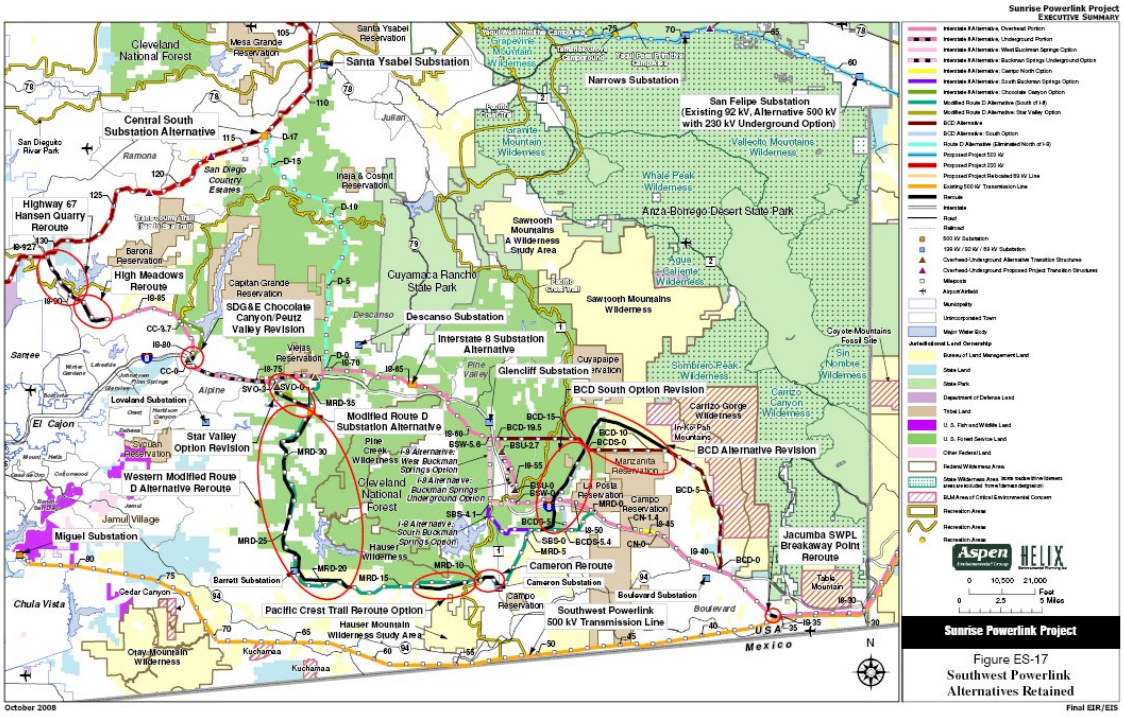
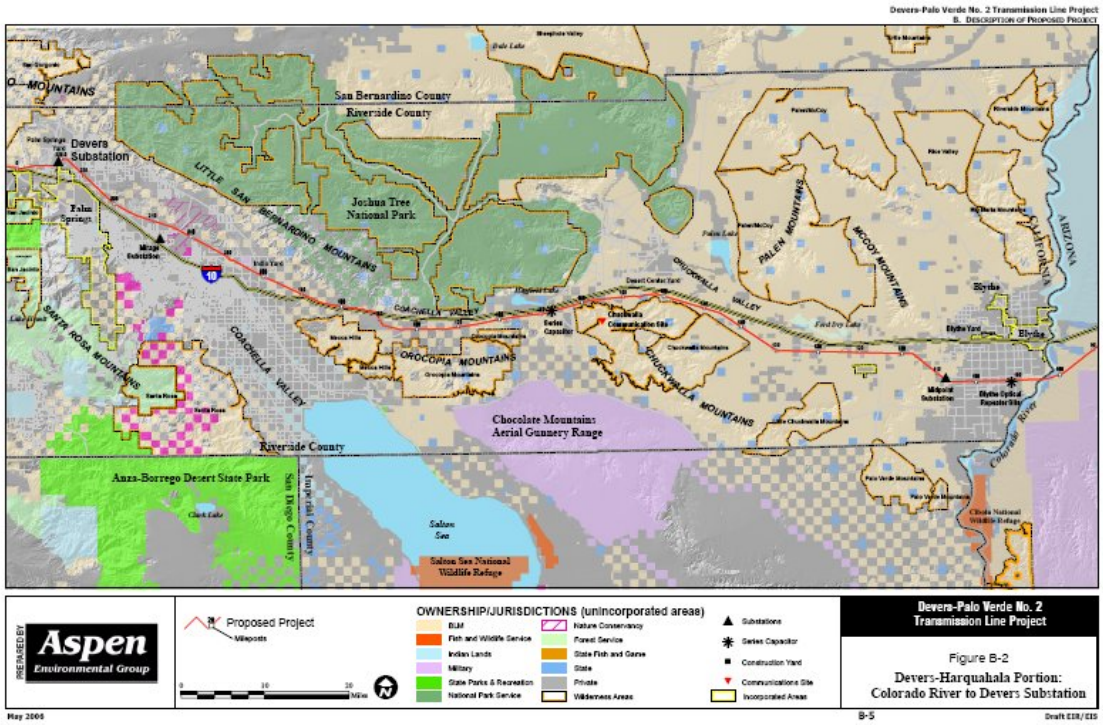

Tehachapi Renewable Transmission Project Segments 1-3
Tehachapi
Highwind
(New)
Windhub
(New)
Tehachapi Wind
Resource Area
CA
San Bernardino
County
Online
Seg
Description
2008
1
Antelope-Pardee 500 kV T/L and Antelope Expansion
2009
2
Antelope-Vincent No.1 500 kV T/L
2009
3
Antelope-Windhub 500 kV & WindHub-Highwind 220 kV
3
Kern County
Los Angeles County
Antelope
(Upgraded)
ANGELES
NATIONAL FOREST
Lancaster
2
1
PALMDALE
Substation
Segments 1-3
Vincent
(Upgraded)
Pardee
SANTA
CLARITA
San Bernardino
County
Ventura
County
ANGELES
NATIONAL FOREST
SAN
FERNANDO

Figure 2: Tehachapi Transmission Project
(Routes shown on this diagram are for illustration purposes only)




Sunrise Powerlink Project
EXECUTIVE SUMMARY
Cleveland National Forest
Mesa Grande Reservation
Santa Ysabel Reservation
Santa Ysabel Substation
Narrows Substation
San Felipe Substation (Existing 92 kV, Alternative 500 kV with 230 kV Underground Option)
Central South Substation Alternative
San Dieguito River Park
Ramona
San Diego Country Estates
Julian
Inaja & Cosmit Reservation
Granite Mountain Wilderness
Vallecito Mountains Wilderness
Whale Peak Wilderness
Anza-Borrego Desert State Park
Highway 67 Hansen Quarry Reroute
Barona Reservation
High Meadows Reroute
Capitan Grande Reservation
SDG&E Chocolate Canyon/Peutz Valley Revision
Cuyamaca Rancho State Park
Descanso
Descanso Substation
Sawtooth Mountains A Wilderness Study Area
Agua Caliente Wilderness
Sawtooth Mountains Wilderness
Interstate 8 Substation Alternative
Viejas Reservation
Pine Valley
Glencliff Substation Alternative
Cuyapaipe Reservation
Sombrero Peak Wilderness
Coyote Mountains Fossil Site
Sin Nombre Wilderness
Santee
Alpine
Loveland Substation
El Cajon
Sycuan Reservation
Star Valley Option Revision
Modified Route D Substation Alternative
BCD South Option Revision
Carrizo Gorge Wilderness
In-Ko-Pah Mountains
Campo Canyon Wilderness
BCD Alternative Revision
Manzanita Reservation
La Posta Reservation
Campo Reservation
Pine Creek Wilderness
I-8 Alternative: West Buckman Springs Option
I-8 Alternative: Buckman Springs Underground Option
Cleveland National Forest
Western Modified Route D Alternative Reroute
Jamul Village
Miguel Substation
I-8 Alternative: South Buckman Springs Option
Hauser Wilderness
Jacumba SWPL Breakaway Point Reroute
Table Mountain
Barrett Substation
Cedar Canyon
Cameron Reroute
Cameron Substation
Campo Reservation
Boulevard Substation
Chula Vista
Pacific Crest Trail Reroute Option
Hauser Mountain Wilderness Study Area
Southwest Powerlink 500 kV Transmission Line
Otay Mountain Wilderness
Kuchamaa
Mexico
USA
N
Aspen Environmental Group
HELIX Environmental Planning
0 10,500 21,000 Feet
0 2.5 5 Miles
Sunrise Powerlink Project
Figure ES-17
Southwest Powerlink Alternatives Retained
October 2008
Final EIR/EIS

.


Devers-Palo Verde No. 2 Transmission Line Project
B. DESCRIPTION OF PROPOSED PROJECT
San Bernardino County
Riverside County
Devers Substation
Palm Springs
Joshua Tree National Park
LITTLE SAN BERNARDINO MOUNTAINS
PALEN MOUNTAINS
McCOY MOUNTAINS
CALIFORNIA
ARIZONA
Blythe
COACHELLA VALLEY
OROCOPIA MOUNTAINS
CHOCOLATE MOUNTAINS
SANTA ROSA MOUNTAINS
Chocolate Mountains Aerial Gunnery Range
Riverside County
Anza-Borrego Desert State Park
San Diego County
Imperial County
Salton Sea
Salton Sea National Wildlife Refuge
Colorado River
Aspen Environmental Group
PREPARED BY
Proposed Project
Milepostts
OWNERSHIP/JURISDICTIONS (unincorporated areas)
BLM
Fish and Wildlife Service
Indian Lands
Military
State Parks & Recreation
National Park Service
Nature Conservancy
Forest Service
State Fish and Game
State
Private
Wilderness Areas
Substations
Series Capacitor
Construction Yard
Communications Site
Incorporated Areas
Devers-Palo Verde No. 2 Transmission Line Project
Figure B-2
Devers-Harquahala Portion: Colorado River to Devers Substation
May 2006
B-5
Draft EIR/EIS

4. Photovoltaics: Technologies, Cost, and Performance

Table of Contents

4. Photovoltaics: Technologies, Cost, and Performance.....1

4.1 Introduction.....1

4.2 Today's PV Technology.....2

4.2.1 Parts of a PV System.....2
4.2.2 PV Module Technologies.....2
4.2.3 PV Performance and Price.....4
4.2.4 Levelized Cost of Energy.....8

4.3 PV Cost and Performance Projections.....9

4.3.1 Increasing PV System Efficiency.....9
4.3.2 Reducing Module Costs.....10
4.3.3 Reducing Balance of Systems Costs.....14
4.3.4 Reducing Supply Chain Margins.....15
4.3.5 Streamlining Regulatory Processes.....16
4.3.6 Total System Costs and Delivered Cost of Energy.....16
4.3.7 Industry Roadmaps.....18
4.3.8 Research and Development.....19

4.4 Materials and Manufacturing Resources.....22

4.4.1 Raw Materials Requirements.....22
4.4.2 Manufacturing Scale-up.....24

4.5 References.....25

List of Figures

Figure 4-1. Basic Components of a Silicon PV Cell (NREL).....3

Figure 4-2. Laboratory Best-Cell Efficiencies for Various PV Technologies.....5

Figure 4-3. Decrease in PV Module Prices with Cumulative Manufactured Capacity.....6

Figure 4-4. Best-PV-System Prices (Using Representative PV-Module Prices) for Residential, Commercial, and Utility-Scale Markets for Several Technologies.....7

DRAFT

Figure 4-5. LCOE for $7/W Residential PV Systems in several U.S. cities in 2009, with and without the Federal Investment Tax Credit 9
Figure 4-6. First Solar's Historical and Projected CapEx 11
Figure 4-7. Projected Multicrystalline Silicon PV Wholesale Module Prices (in 2009 U.S. Dollars) 13
Figure 4-8. Projected Monocrystalline Silicon Wholesale PV Module Prices (in 2009 U.S. Dollars) 13
Figure 4-9. Balance of System Costs (Before Installer Profit) for Several PV Multiple Applications and a Range of Module Efficiencies 15
Figure 4-10. PV LCOEs by Year and Market Segment 17
Figure 4-11. SunPower's Roadmap for Decreasing Monocrystalline Silicon Module Manufacturing Costs from $2/W to $1/W (2009) 18
Figure 4-12. First Solar's Roadmap for Decreasing CdTe Module Costs to $0.52–$0.63/W (2009) 19
Figure 4-13. First Solar's Roadmap for Decreasing BOS Costs (2009) 19
Figure 4-14. Key PV Material Availability Forecast 24

List of Tables

Table 4-1. Estimated Module Parameters, 2010, Used in Analysis (Figure 6) 5
Table 4-2. Installed Costs for Systems with Multicrystalline Modules by Year and Market Segment 17
Table 4-3. Corporate Roadmaps to 2014 20
Table 4-4. Possible Materials Needed in 2030 per GW of Newly Installed Systems if Material-Reduction Strategies are Successful 24

DRAFT

4. Photovoltaics: Technologies, Cost, and Performance

4.1 Introduction

The Solar Vision evaluates the technical and economic implications of meeting 10% and 20% of U.S. electricity demand using solar technologies by 2030, about half with photovoltaics (PV) and half with concentrating solar power (CSP). PV markets would have to see very strong growth in the U.S., from just over 1 gigawatt (GW) of installed capacity in 2010 to several hundred GW by 2030. Although this represents significant market growth, both the magnitude and pace are feasible based on recent global growth trends and will not be constrained by the availability of materials, land, or manufacturing scale-up.

Achieving steady PV cost and performance improvements is essential to rapid PV market growth. PV technologies have been demonstrated commercially since the early 1970s and have undergone continual R&D-driven cost and performance improvements. All PV technologies have benefitted from significant cell efficiencies improvements and cost reductions, particularly during the past decade. Mature PV technologies—such as crystalline silicon, cadmium telluride (CdTe), and amorphous silicon (a-Si)—have been manufactured and deployed at the GW scale. These technologies have clear pathways to achieving significant cost reductions, with evolutionary technology improvements and more efficient manufacturing methods, reduced supply chain inefficiencies, and benefitting from economies of scale as markets continue to grow and mature. Several emerging PV technologies—including copper indium (gallium) diselenide (CIS or CIGS) and concentrating PV (CPV)—have seen an accelerating pace of capital investment which is moving these technologies toward full-scale production.

In the United States, federal and state government incentives have made PV an attractive investment in markets ranging from residential and commercial rooftops, to distributed and central wholesale markets. These incentives have accelerated PV cost and performance improvements, and stimulated private investment supporting PV R&D and manufacturing scale-up. As PV costs continue to decline, unsubsidized PV electricity will be able to compete directly with retail electricity rates in rooftop markets and wholesale electricity rates in utility markets, especially in regions with a good solar resource and high electricity rates like California. In addition to becoming cost competitive, distributed utility-scale (also referred to as wholesale distributed generation) PV can be sited near load centers, thus reducing grid congestion and the need for costly transmission and distribution infrastructure.

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This chapter evaluates the current cost, performance, and potential of several PV technologies. A detailed, bottom-up engineering analysis identifies opportunities for continued PV cost reductions, and these are compared with historical trends and industry roadmaps. Key challenges to achieving Vision PV penetration targets are evaluated including manufacturing scale-up, and the supply and cost of feedstock materials. This analysis makes clear that continued cost reductions and research and development (R&D) investment will be essential to reaching Vision growth targets, but no technology breakthroughs will be required. The market growth outlined in Vision scenarios could be reached using today's demonstrated PV technology, and the successful development and demonstration of emerging PV technologies would enable reaching Vision targets at lower cost.

4.2 Today's PV Technology

Today's PV technology is the result of decades of performance and price improvements. This section describes the history of these improvements and the current status of PV technology.

4.2.1 Parts of a PV System

PV systems are typically classified into two subsystems for the purposes of understanding technologies and costs: PV modules and balance of systems (BOS)[1]. PV modules are fabricated from several interconnected PV cells, which convert sunlight directly into electricity. PV cells are fabricated from semiconductor materials that enable photons to "knock" electrons out of a molecular lattice, leaving a freed electron and "hole" pair that diffuse in an electric field to separate contacts, generating direct current (DC) electricity. This "photoelectric effect" has most commonly been generated with materials such as crystalline silicon and thin films with semiconductor-like properties (e.g. amorphous silicon, CdTe, and CIGS). For additional detail on the physics of PV cells, there are several good references such as *Luque & Hegedus* (2003).

The DC electricity generated by the PV module is frequently converted to alternating current (AC) electricity using an inverter, and stepped-up to the proper voltage for customer use or export to the grid using a transformer. The components associated with this delivery process, such as inverters, transformers, electrical protection devices, wiring, and monitoring equipment, are all a part of the BOS. In addition, the BOS also includes structural components for installing PV modules, which include fixed mounting frames and sun-tracking systems.

4.2.2 PV Module Technologies

Several crystalline silicon and thin film PV technologies have been demonstrated commercially on a large scale. Concentrating PV (CPV) has yet to reach the same level of market penetration but offers potential cost and performance advantages. Additionally, several emerging PV technologies may be technically and economically competitive in the future.

[1] BOS is sometimes limited to mounting and wiring hardware and does not include the inverter, labor or permitting fees. Here and elsewhere in the Vision study, BOS refers to the inverter, mounting and wiring hardware, installation, and permitting fees.

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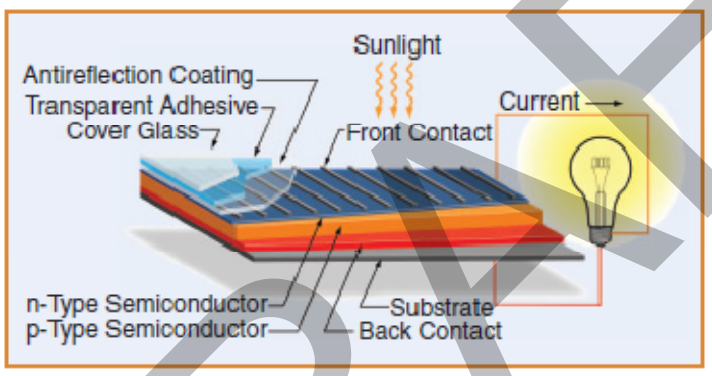
Crystalline Silicon

Crystalline silicon technologies constitute about 85% of the current PV market. This type of module has demonstrated operational lifetimes of more than 25 years.

There are two general types of crystalline, or wafer-based, silicon PV: monocrystalline and multicrystalline. Monocrystalline semiconductor wafers are cut from single-crystal silicon ingots. Multicrystalline PV wafers are cut from directionally solidified blocks or grown in thin sheets. For both types, the silicon is processed to create an internal electric field, and positive and negative electrical connections are added to wafers to form cells, (Figure 4-1). Standard cell processes are used to complete the circuit for both mono- and multicrystalline cells, and multiple cells are linked and encapsulated to form modules.

Figure 4-1. Basic Components of a Silicon PV Cell (NREL)



Although standard cell architectures dominate the market today, non-standard architectures are growing in importance because they offer the potential for significantly higher efficiency. The rated DC efficiencies of standard crystalline silicon PV modules are approximately 13%–15%. Non-standard cell architectures tend to use high-quality monocrystalline wafers and more sophisticated processing to achieve module efficiencies of approximately 17% to 19%.

Thin Film

Thin film PV cells consist of a semiconducting layer—most commonly CdTe, a-Si, or alloys of CIGS—a few microns thick, which is about 100 times thinner than crystalline silicon cells. This layer is typically deposited on a low-cost substrate inside a vacuum chamber. A number of firms are pursuing lower cost non-vacuum approaches for manufacturing thin film technologies. Glass is a common substrate, but thin films can also be deposited on flexible substrates such as metal or plastics, which can be incorporated into building materials. Thin film modules have lower peak DC efficiencies than crystalline silicon modules: approximately 9%–11% efficiency for CdTe, 8%–12% efficiency for CIGS, and 6-8% efficiency for a-Si. Among the thin films, CdTe has experienced significantly higher market growth over the last decade than the other thin film technologies.

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Concentrating PV

CPV technologies use mirrors or lenses to concentrate sunlight 2–1,500 times onto a high-efficiency silicon or multijunction[2] PV cell. The use of inexpensive materials such as glass and steel to focus sunlight reduces the amount of semiconductor material required for a given unit of output. Recent improvements in the efficiency of multijunction PV cells (over 40%) offer the potential for very high power density. There is renewed interest, and investment, in CPV for utility-scale applications.

Noncommercial PV Options

A number of other PV materials—frequently referred to as third-generation PV—are being developed. Dye-sensitized solar cells use dye molecules in an electrolyte solution to absorb solar radiation and have demonstrated efficiencies up to 12%. Organic solar cells, based on plastics with semiconductor properties, have demonstrated laboratory efficiencies up to about 8%; organic modules have the potential for low-cost manufacturing using existing printing and lamination technologies (Shaheen et al. 2005). Challenges to commercialization of organic and dye-sensitized cells include the absorber layer's degradation rate and heightened moisture barrier requirements. Quantum dots—nanospheres with physical properties similar to both semiconductors and molecules—absorb solar radiation at multiple frequencies but have not yet been used to produce efficient PV cells. Each of these technologies could be a source of low-cost PV cells in the future. However, the Vision study only evaluates cost and performance improvements for commercially proven technologies.

4.2.3 PV Performance and Price

The performance of PV technologies has improved substantially over the past several decades, based on technical innovation, improved PV manufacturing processes, and growing PV markets. All of these factors have contributed to a downward trend in PV prices.

PV Performance

PV performance has improved steadily over the past four decades. Figure 4-2 shows the increase in best-cell efficiencies by PV technology. These are laboratory prototype cells, developed through successful R&D. A number of challenges—such as simplifying or modifying cell properties to improve manufacturability and economics—must be overcome before laboratory cells lead to commercial products. Some cell efficiency improvements are simply too expensive to implement at the commercial scale. Further challenges are encountered as small cells are linked together (crystalline silicon) or made in much larger areas (thin films) then encapsulated to form commercial modules. Commercial module efficiencies typically track best-cell efficiency improvements, with a time and performance lag (Table 4-1).

[2] Multijunction cells consist of different semiconductor layers stacked on top of each other, each with unique energy "bandgaps" that absorb different parts of the solar spectrum. This allows multijunction cells to convert more of the sun's energy into electricity and thus attain higher DC efficiencies than conventional cells.

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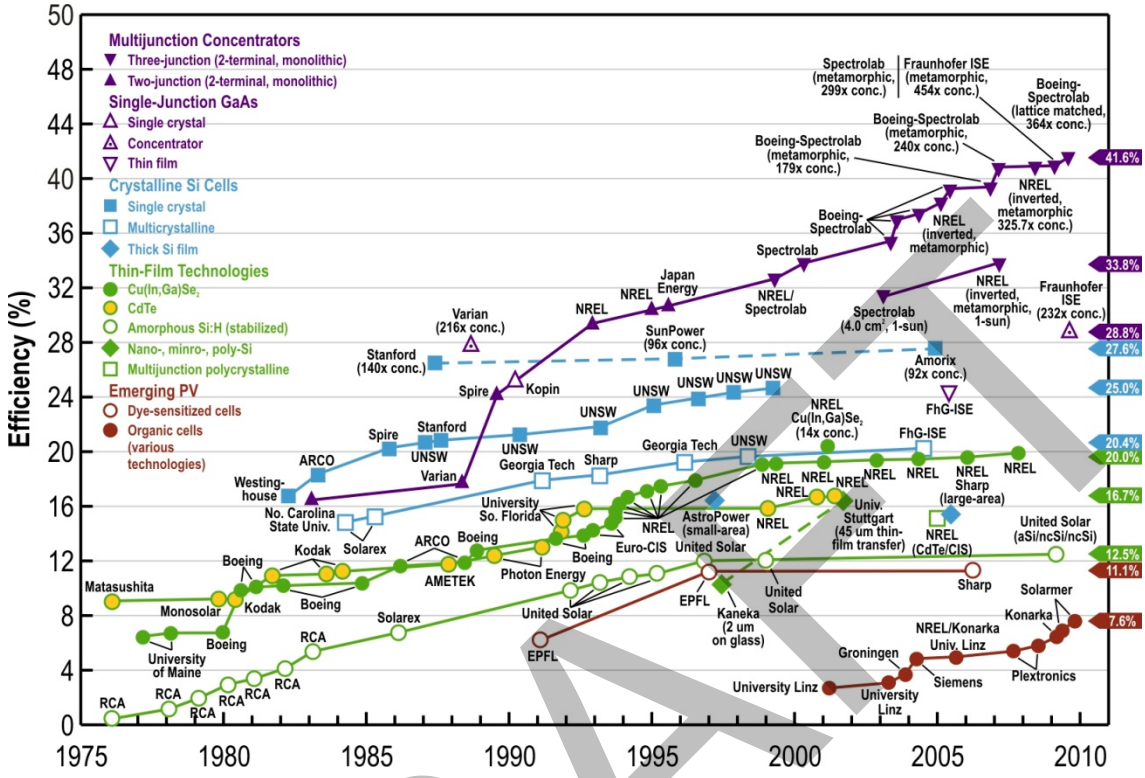
Figure 4-2. Laboratory Best-Cell Efficiencies for Various PV Technologies



Source: Kazmerski (2009)

Table 4-1. Estimated Module Parameters, 2010, Used in Analysis (Figure 6)

Technology	Best-Cell Efficiency	Commercial Module Efficiency	Production Module *Cost* ($/W)[3]
Monocrystalline silicon[4]	25%	14%	$1.35
Multicrystalline silicon	20%	14%	$1.28
CdTe	16.7%	11%	$0.90
a-Si[5]	12.5%	7%	$1.50
CIGS	20.4%	11%	$1.75
Low-concentration CPV with 20%-efficient silicon cells	—	15%	$2.20
High-concentration CPV with 38%-efficient III-V multijunction cells	—	29%	$1.75

[3] For each technology, there is a distribution of costs reflecting company-specific product, technology, and manufacturing assumptions.
[4] The cost and efficiency represents average production characteristics. Non-standard monocrystalline technologies—such as SunPower's rear-point-contact cell (19.3% efficiency) and Sanyo's HIT-cell-based module (17.1% efficiency)—are now commercially available.
[5] a-Si modules range from single to triple junction, including microcrystalline layers.

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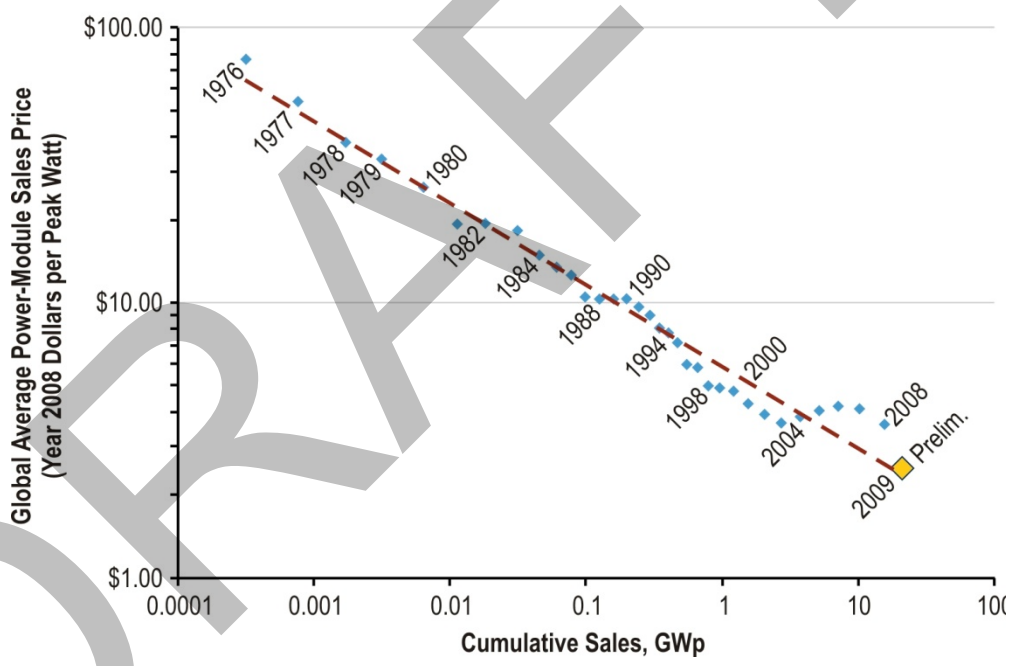
PV Module Prices

PV module prices are strongly influenced by the most available PV technology (i.e. crystalline silicon), and prices oscillate when supply and demand are mismatched (Figure 4-3). The most available PV technologies to date have been monocrystalline and multicrystalline silicon, although CdTe market share is growing rapidly (Grama and Bradford 2008). PV prices from 2005–2008 reflect a supply-constrained market, in which the price of polysilicon feedstocks for crystalline silicon PV, and margins, stayed high. Since 2009, polysilicon supply has increased without an equivalent increase in demand, reducing polysilicon prices dramatically. As a result, crystalline silicon PV manufacturing costs and end-use prices declined considerably in 2009, returning to the long-term trend line.

Figure 4-3. Decrease in PV Module Prices with Cumulative Manufactured Capacity



Sources: Adapted from Mints (2009) and Mints (2010)

PV System Prices

To better understand PV cost and performance, and how much these can improve over time, a bottom-up engineering analysis of PV systems was conducted as part of the Vision study. The cost of each process in the production of crystalline silicon PV systems was analyzed based on conversations with vendors and manufacturers. This analysis, along with cost data reported by a range of manufacturers for each of the other technologies, was used to evaluate the drivers behind today's PV system costs as well as the potential for future cost reductions.

Efficiency is one of the factors that contributes to PV system cost. Table 4-1 shows representative production-module efficiencies by technology—from a survey of product datasheets (von Roedern 2010)—along with corresponding best-cell efficiencies. Table 4-1 also shows representative module manufacturing costs,

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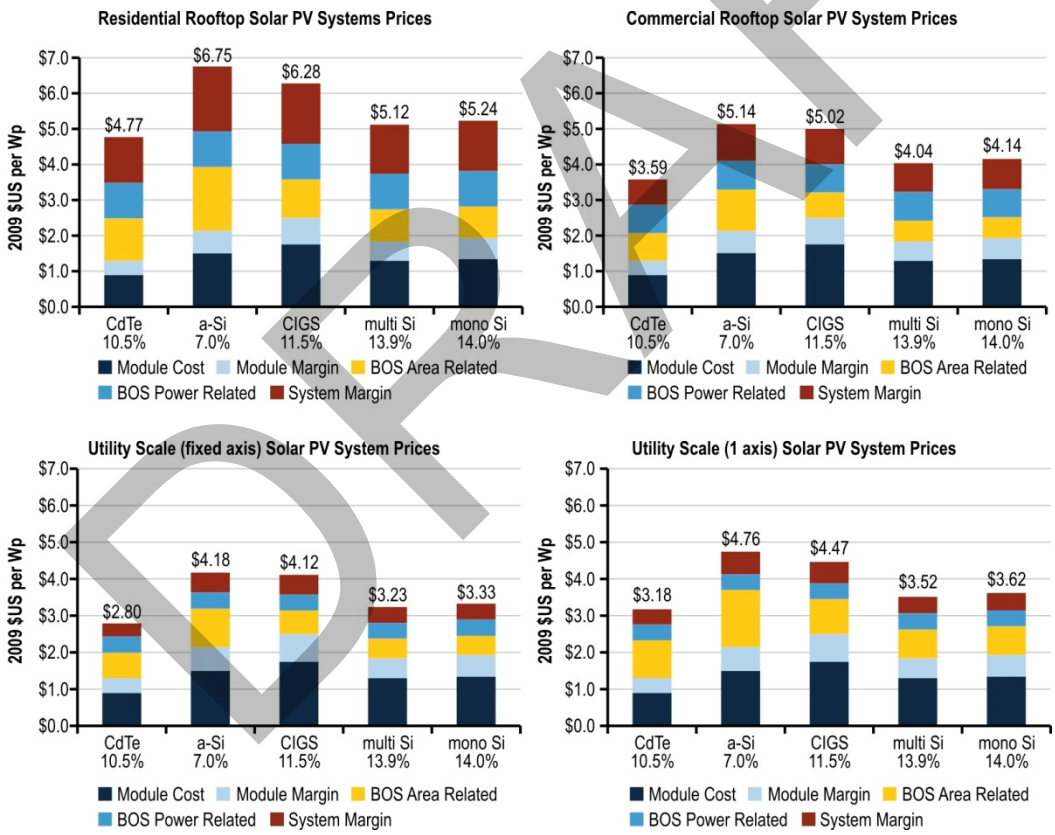
which vary by manufacturer and technology. Cost leaders for each technology, such as Trina Solar, have reported lower costs ($1.24/Wp for mixed mono- and multicrystalline silicon) that are not necessarily reflective of all manufacturers' processes, products, and financial assumptions (Trina Solar 2009).

Figure 4-4 summarizes the results of the bottom-up engineering analysis, estimating "best" PV system prices (in 2010) for the residential, commercial, and utility markets for several technologies. These prices represent estimated manufacturing costs plus a reasonable margin at each stage of the supply chain based on detailed discussions with numerous module and component suppliers. Component and system prices vary by market segment owing to these margin assumptions, which reflect the various channels to market. BOS assumptions were similarly developed through conversations with suppliers and installers. BOS costs are separated into area-related and power-related components to reflect the decrease in BOS costs with increasing module efficiency.

Figure 4-4. Best-PV-System Prices (Using Representative PV-Module Prices) for Residential, Commercial, and Utility-Scale Markets for Several Technologies



Most distribution, siting, and regulatory inefficiencies in the marketplace are not included in the estimates. These inefficiencies vary by region. In some regions (e.g., Germany), they are small, and actual market prices approximate the estimate of "best" system prices. In other regions (e.g., the United States), they are large and thus create a significant gap between average prices in the market and these best-price estimates.

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Residential systems have the highest prices because of their small size (2–4 kW), fragmented distribution channels, and high marketing and installation costs. Residential PV modules typically pass through multiple distributors between the factory gate and local installers. Installers then add their own markups and associated costs.

Commercial systems, such as those on the flat roofs of big-box retail stores, are larger than residential systems (up to 2 MW). However, they are not typically large enough to attain all economies of scale in purchasing components and installation labor. The prices of commercial systems are about 20% lower than the prices of residential systems, but they are higher than the prices of utility-scale systems.

Utility-scale systems have the lowest per-watt price. These systems are large enough to realize significant economies of scale in component purchasing and installation labor, significantly reducing system margins. CdTe appears to have the lowest price for all applications. However, the best PV system prices do not represent prices typically seen in the marketplace, because system prices are set by crystalline silicon PV. Multicrystalline and monocrystalline silicon PV systems are only slightly more expensive than those shown in Figure 4-4, now that polysilicon feedstock prices have dropped. CIGS and a-Si have the highest 'best cost' estimates. CIGS is a relatively immature technology, and higher-volume manufacturing could result in decreasing CIGS prices. This is merely a snapshot of today's competitive landscape, as the relative 'best cost' of all PV technologies could change significantly as R&D advances are adapted into commercial products (e.g. the recent emergence of CdTe).

4.2.4 Levelized Cost of Energy

Levelized cost of energy (LCOE) is the ratio of an electricity-generation system's costs—installed cost plus lifetime operation and maintenance (O&M) costs—to the electricity generated by the system over its operational lifetime, given in units of cents/kWh. The calculation of LCOE is highly sensitive to installed system cost, O&M costs, local solar resource and climate, panel orientation, financing, system lifetime, taxation, and policy. Thus, PV LCOE estimates vary widely.

Figure 4-5 shows the LCOE for past residential PV systems priced at $7/W in three U.S. cities; this price is 40% higher than the approximately $5/W residential systems shown in Figure 4-4, representing the inefficiencies in the U.S. market that reduce the availability of best-price systems. The LCOE ranges are about $0.17–$0.22/kWh with the 30% federal ITC and $0.24–$0.31/kWh without the ITC. These estimates are based on the following assumptions: 80% of the system is financed via a 30-year mortgage at a 6% interest rate; the customer has an effective tax rate of 33% and a discount rate of 5.4%;[6] the customer incurs $380/kW for inverter replacement and related labor costs in year 10; annual O&M expenses are $36/kW-yr; the system output degradation rate is 1.0%/year; and no state or local incentives are included.

The LCOE for commercial and utility-scale PV systems is generally much lower than for residential PV systems located in the same regions, mainly because

[6] The discount rate is in nominal terms and equal to the customer's after-tax weighted average cost of capital (WACC), computed from the cost of debt of 6.0% and cost of equity of 10.8% (based on long-term historical returns of the S&P 500).

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Figure 4-5. LCOE for $7/W Residential PV Systems in several U.S. cities in 2009, with and without the Federal Investment Tax Credit

Source: DOE (2010)

commercial and utility-scale PV systems have significantly lower installed prices per watt. O&M costs per watt also tend to decrease as PV system size increases owing to more advantageous economies of scale and other factors. The output of large systems can be enhanced by using tracking systems, and larger, optimized, better-maintained PV systems can produce electricity more efficiently and consistently. In addition, the largest systems are likely to be disproportionately built in regions with the best solar resource (e.g., Arizona).

4.3 PV Cost and Performance Projections

The price of PV modules has decreased 20-fold since the 1970s, and significant future cost reductions are projected. Although a number of factors will drive these cost reductions, five areas are key: increasing PV system efficiency, reducing module costs, reducing BOS costs, reducing supply chain margins, and improving market efficiencies. No technological breakthroughs are required to achieve substantial cost reductions, and the Vision analysis considers only commercially proven PV technologies. The potential of emerging technologies (see Section 4.2.2) is less quantifiable but still substantial.[7]

4.3.1 Increasing PV System Efficiency

Consistent improvements in efficiency have been realized for virtually every PV technology (Figure 4-2). This trend is projected to continue owing to R&D improvements that produce higher best-cell efficiencies, manufacturing technology

[7] Once new technologies become market leaders, they can rapidly gain market share. For example, First Solar, Inc. (www.firstsolar.com) launched commercial CdTe PV cells in 2002, and within 7 years it had become the world's largest PV manufacturer. Although the potential of emerging technologies is not considered in this study, it should not be underestimated.

improvements that advance commercial modules towards best-cell efficiencies, and system improvements such as converting DC electricity into AC electricity more efficiently. These efficiency improvements will drive down PV module and system costs.

Continued efforts are required to achieve the necessary efficiency improvements. Increasing PV-system efficiency is technically challenging and rewards sophisticated observations, ideas, and experiments. Multi-year (even multi-decade) R&D programs such as the DOE PV Program, which drove the improvements shown in Figure 4-2, are often required to improve the industry's understanding of a technology and then transfer this knowledge to commercial production.

4.3.2 Reducing Module Costs

The PV market is dominated by crystalline silicon modules, with the market share of CdTe modules growing rapidly. Cost reduction potentials are unique to each technology, but reducing material costs and improving manufacturing processes are key strategies for all technologies.

Reducing Material Costs

Active semiconductor material (the material that converts sunlight into electricity) is the most complex and expensive component of a PV module. Polysilicon semiconductor material, the feedstock used to grow crystalline silicon PV, was a large component of early module costs, and remains a major component of today's module costs. However, polysilicon feedstock costs have been reduced via several methods:

1. Making thinner wafers (reducing the industry average from 300 to as low as 140 microns)
2. Minimizing polysilicon losses during the wafering process
3. Improving polysilicon scrap recycling capabilities and costs
4. Introducing low-cost polysilicon feedstock purification methods to reduce energy and capital-equipment costs
5. Developing new PV technologies that require minimal or no polysilicon and minimizing the use of all semiconductor materials, e.g., by reducing the semiconductor thickness in thin films or using CPV technologies to reduce the required semiconductor area

Costs for thin film active semiconductor material vary from a few dollars per square meter to tens of dollars per square meter (which can be almost as much crystalline silicon semiconductor material, on a per-watt basis). The wide range of costs among different thin film technologies results from the use of small amounts of non-abundant materials and the inefficient use of expensive, highly processed sources (e.g., sputtering targets or certain gases).

After the active semiconductor material, the front and back cell contacts are the next most-expensive materials in PV modules. PV manufacturers strive to design cells that balance the cost of these materials with their effect on module performance.

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Module-encapsulation materials—such as front and back glass and adhesive to bind the layers and the cells—add considerable cost to PV modules. Again, manufacturers must balance the benefits of using less-expensive materials against resulting effects on module performance; modules with better reliability and longer lifetimes have lower lifetime costs. Other materials to be considered are those used in edge seals, frames, mounting hardware, cell interconnections, and bus bars. A junction box with external wires costs several dollars per module.

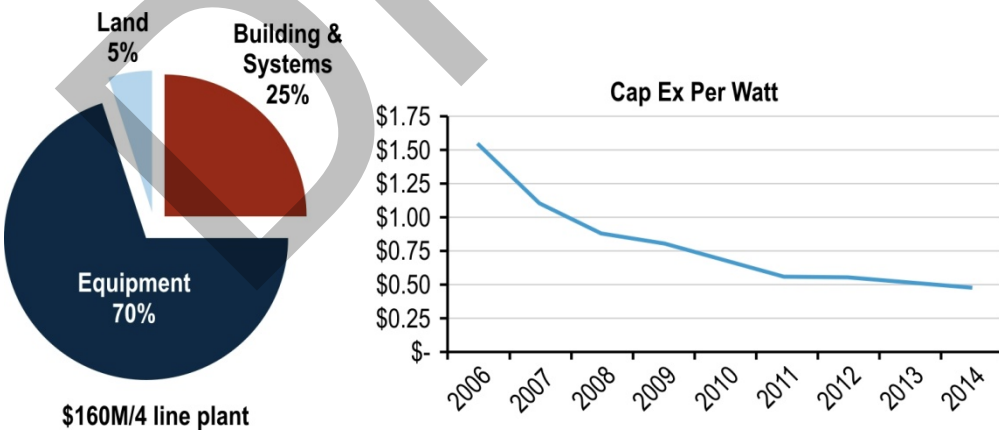
Another way manufacturers can reduce material costs is to become more vertically integrated. Even partial in-house supply of materials that have volatile prices will help a manufacturer have access to the best-available market pricing.

Improving Manufacturing Processes

Manufacturing costs are a major component of module costs. Manufacturing equipment costs are measured in dollars per watt of annual factory output, known as the "CapEx" (which should not be confused with per-watt module and system costs). Because equipment is depreciated over time (e.g., 7 years), its contribution to module cost is about one seventh of this cost per annual watt of module output, after adjustments are made to account for the cost of capital. There are also equipment maintenance costs.

Several factors affect manufacturing costs, including speed, yield, labor, and energy. Increasing manufacturing speed results in higher throughput and lower costs per watt. For example, First Solar makes its CdTe layer in approximately 1 minute, giving it one of the lowest CapEx levels (less than $1 per watt) among fully vertically integrated module manufacturers (Figure 4-6). Some manufacturers have a CapEx as high as $3 per watt. Speed can be increased by measures such as increasing deposition rates, increasing the width of an in-line reaction chamber, and building large furnaces that can process many substrates at once.

Figure 4-6. First Solar's Historical and Projected CapEx



Source: First Solar (2009)

Increasing yield—the proportion of manufactured product that meets commercial specifications—is another way to increase throughput and reduce costs per watt. Crystalline silicon production lines typically operate at yields of at least 93%. However, yields can vary widely depending on the quality of the incoming material

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(e.g., wafers) and the desired minimum product quality (e.g., cell efficiency). A wide range of acceptable cell efficiencies may contribute to module stringing losses later. As virgin polysilicon prices have dropped, the use of recycled silicon in casting operations has diminished, increasing the overall quality of materials on the market. The point in the manufacturing process at which defective parts are identified is also critical. Bad parts that are not identified until the end of a process increase costs more than those identified at the beginning.

Reducing labor and energy use requirements also reduces manufacturing costs. Labor costs depend on the maturity of the manufacturing approach and the local labor rates. It is almost certain that labor costs will decline as PV matures and manufacturing plants become larger and more automated. Energy use can be reduced by implementing several strategies, including faster processing techniques, using lower temperature processes, and replacing vacuum with non-vacuum processes where possible. Past improvements of this sort have lowered the PV energy payback periods to 1–3 years, which has important policy implications (see the discussion of GHG emissions in Chapter 8).

Reducing Module-Shipping Costs

The PV industry relies on a global supply chain. As the industry matures, the economies-of-scale advantages captured by large suppliers likely will increase the average distance that a PV product travels from manufacturer to installer. Sea-transport (container) rates are currently at historic lows, and the cost of shipping modules by sea is approximately $0.05–$0.06/W (Goodrich 2010), adding 5-10% to module costs.

Many PV components—including polysilicon, wafers, and even cells—can be shipped cheaply. The glass content of both thin film and crystalline silicon modules adds the most to shipping costs, because glass is dense and tends to fill a shipping container based on weight rather than volume. Lower-efficiency modules have more glass weight—and thus cost more to ship—per unit of power.

Crystalline silicon module manufacturers frequently have a disaggregated supply chain, where wafers, cells, and modules are commonly manufactured by different companies in different locations. Thin film manufacturers typically have an aggregated supply chain. This is an advantage for reducing crystalline silicon shipping costs, because module manufacturing facilities can be sited near end-use markets, eliminating the need for ocean transport and associated costs. Crystalline wafers and cells are significantly less heavy, since they lack encapsulating materials, and can be shipped for significantly less cost.

Cost Projections

Figure 4-7 and Figure 4-8 illustrate cost-reduction potential for typical multicrystalline and monocrystalline silicon PV modules. Component costs were calculated using a detailed PV-manufacturing cost model intended to simulate "typical" silicon PV module production costs (Goodrich and Hsu 2010), and do not include incentives. Actual costs will vary by company and situation (depreciation schedule, taxes, labor rates, etc.). The 2010 module costs represent manufacturing processes currently in use. Cost reductions result primarily from increased efficiency and reduced polysilicon use (thinner wafers, greater yields) and prices.

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Figure 4-7. Projected Multicrystalline Silicon PV Wholesale Module Prices (in 2009 U.S. Dollars)

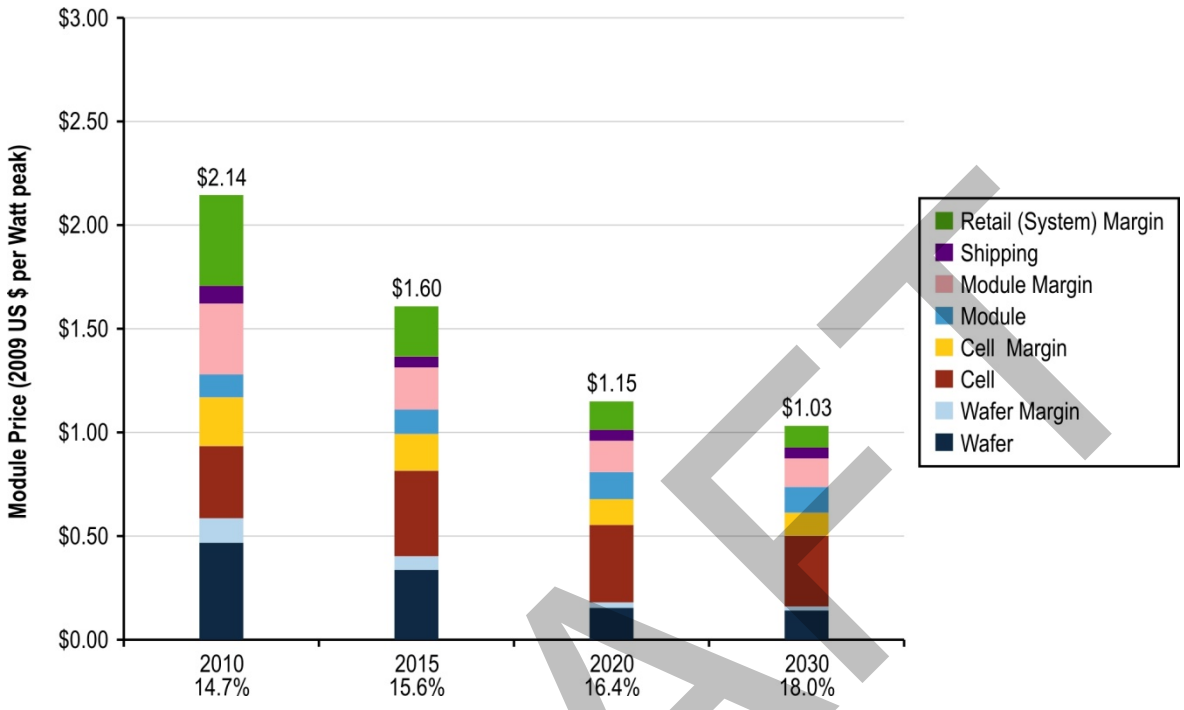
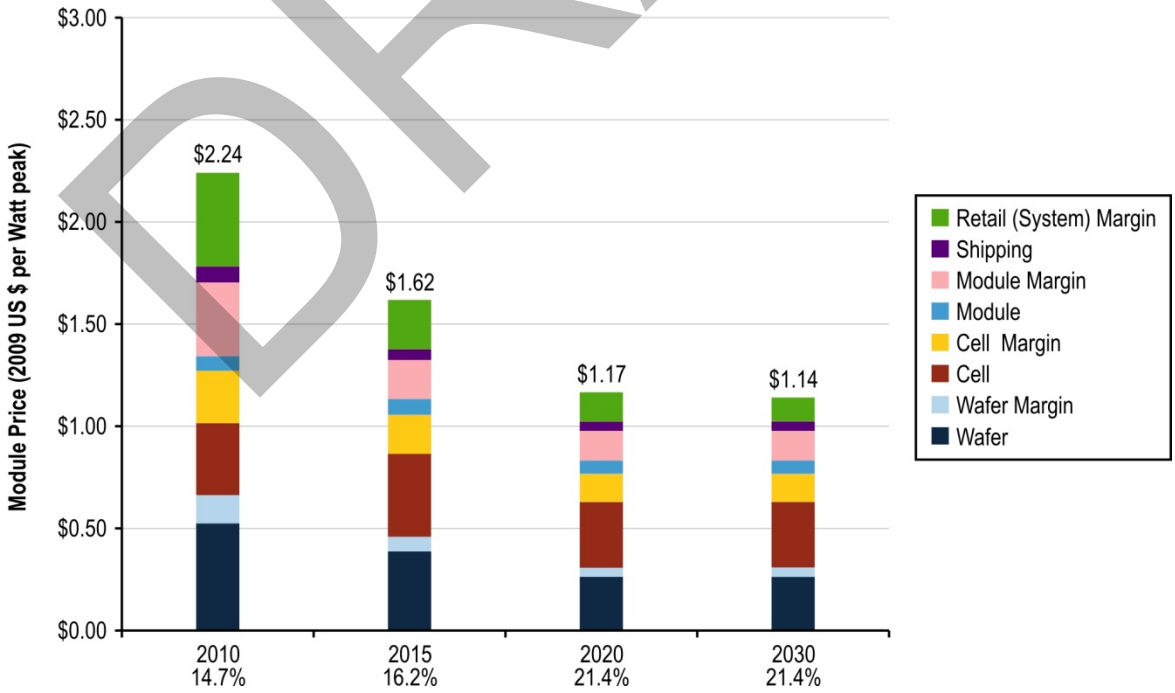


Figure 4-8. Projected Monocrystalline Silicon Wholesale PV Module Prices (in 2009 U.S. Dollars)



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Product efficiency gains are projected to be achieved through multiple pathways. For example, using higher-quality feedstocks, reducing shadowing losses due to front-side cell contacts, and implementing advanced cell architectures. By 2015, most monocrystalline and multicrystalline modules are projected to be made using a selective-emitter technology and fine (~40 micron wide) front contacts. By 2020, monocrystalline modules are projected to use back contacts.[8]

Another large component of the cost reductions is decreasing profit margins at each step of the supply chain, resulting from increased competition. Minimum sustainable profit margins have been forecast using detailed manufacturing cost and pro forma financial models. Similar cost-reduction potentials are likely for thin film technologies, although the actual rate of cost reduction and efficiency enhancement will vary by technology.

4.3.3 Reducing Balance of Systems Costs

BOS includes inverters, transformers, support structures (including trackers), mounting hardware, electrical protection devices, wiring, monitoring equipment, shipping, land, installation labor, permitting, and fees. BOS costs frequently add $1-$4/W, depending on the size and type of PV system, its location, and margins. In many PV applications, BOS costs are higher than module costs, and it is becoming increasingly important to reduce these costs in tandem with reducing module costs.

Major improvements in BOS cost are likely to come from reducing the cost of installation, likely by simplifying designs to reduce installation time and effort and streamlining distribution and installation margins as the industry grows. Additional BOS cost reductions are likely to come from increasing inverter efficiency and durability, improving module matching to reduce electrical-mismatch losses, and reducing support structure and tracking costs.

Figure 4-9 shows the efficiency-dependence of BOS costs (2010 US$) using a detailed cost model developed for the Vision study. These costs do not include system integrator margins. Increasing system efficiency lowers the area-dependent component of BOS costs (installation labor, support and tracking structures, wiring, and land costs) since fewer modules are required to reach a given system capacity. In this way, BOS costs are reduced even when the cost of structural and tracking components, and labor remain fixed.

Utility-scale, ground-mounted systems can be configured in various ways, each with a different effect on BOS costs. It is possible to gain approximately 25% more annual output from a module using a one-axis tracking array. Tracking also increases PV output in the mornings and afternoons, the latter being especially valuable in regions with strong afternoon cooling loads. This additional PV output incurs the cost of the tracking system, and tracking is economic if its benefits outweigh its costs. Today, tracking systems are frequently used with crystalline silicon PV in utility-scale installations. Thin film PV utility-scale installations do not as yet use tracking systems, but as their efficiencies increase, they may evolve in that direction.

[8] Multicrystalline modules are not projected to implement all back contacts owing to material performance and lifetime limitations.

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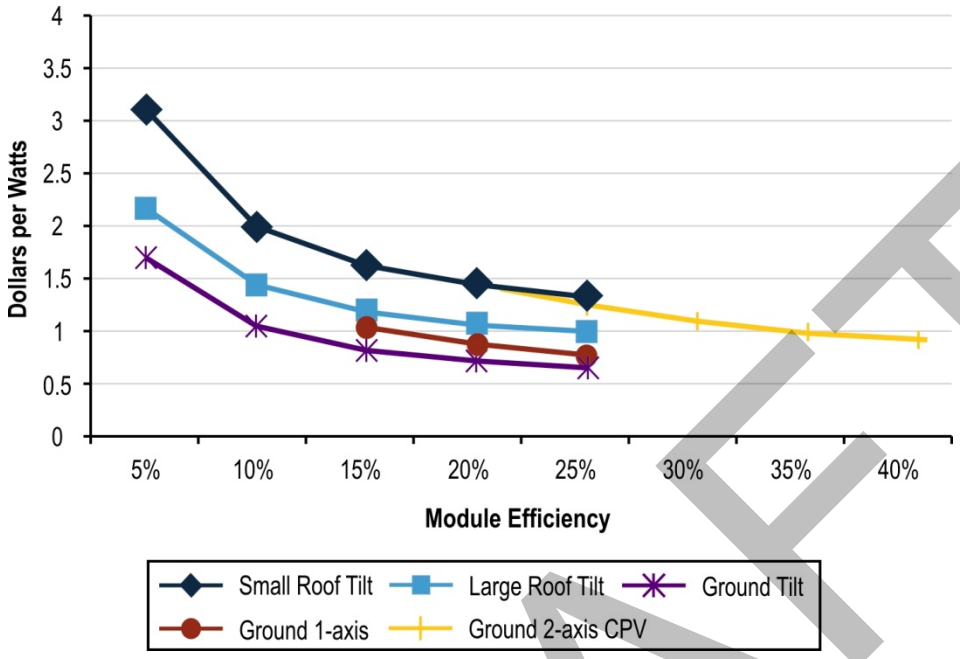
Figure 4-9. Balance of System Costs (Before Installer Profit) for Several PV Multiple Applications and a Range of Module Efficiencies



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CPV is an emerging approach to utility-scale systems, especially in arid regions that receive high levels of the direct-beam insolation CPV needs. The types of tracking used in CPV systems influences BOS costs considerably: both equipment costs and electricity production increase with increasing tracking-system sophistication (i.e., from no tracking to 1-axis tracking to 2-axis tracking). Thus, tracking costs are a tradeoff between equipment costs and the additional electricity generation enabled. CPV systems with low concentration ratios (2–10 "suns") can use no tracking or can use 1- or 2-axis tracking. CPV systems with higher concentration use 2-axis tracking.

4.3.4 Reducing Supply Chain Margins

The final PV price paid by a consumer can include significant margins—representing both profit and overhead—charged by suppliers, manufacturers, distributors, and the retailer/installer (Figure 4-4, Figure 4-7, and Figure 4-8). These margins are far higher than those charged by manufacturers and suppliers of mature electricity-generation technologies. A number of factors can cause high PV margins, particularly for smaller systems.

Installers of large utility-scale or commercial rooftop systems frequently negotiate module costs directly with manufacturers and the prices they receive do not include distribution and retail margins. Also, the margin charged by large-system installers is frequently lower (on a per-kW basis) than that charged by smaller-system installers. Residential-system installers typically procure modules and mounting hardware from distributors, paying an additional margin before charging a typically

higher per-kW installation margin. This can nearly double the cost of higher-cost residential systems compared with lower-cost utility and commercial systems.

PV margins—and the cost differential between large and small systems—likely will decrease as the markets grow and mature, competition streamlines the supply chain, and personnel requirements per unit of capacity decrease. In addition, installer margins likely will decrease as PV systems become simpler to install and more competition is created by growth in the number of installers. Similarly, the absolute magnitude of margins falls as the cost of PV components falls; this has had a major effect in the past few years as module costs have fallen by a factor of three.

4.3.5 Streamlining Regulatory Processes

Several regulatory requirements increase the cost of developing PV resources—including costs related to site acquisition, surveys, environmental studies, permitting, and government fees. These vary by region, but tend to become standardized and streamlined, reducing costs, as PV markets grow and mature. This has been the case in market-leading countries such as Germany and Japan.

4.3.6 Total System Costs and Delivered Cost of Energy

Aggregating all of the component costs, including the cost of modules, BOS (inverter, tracker, other materials, installation labor, permitting and regulatory compliance, and installer overhead) yields the total system cost. Viewed from the perspective of the final system owner, these component costs are inclusive of their respective margins and are thus referred to as prices. Table 4-2 shows current and projected installed costs for systems using multicrystalline silicon modules. Multicrystalline prices are shown as 'representative' of the PV market because they account for nearly 50% market share and have intermediate efficiencies (DOE 2010). In addition to including component cost margins, Table 4-2 shows average system prices, as opposed to the 'best cost' systems presented in Figure 4-7.

Figure 4-10 converts the total installed system costs in Table 4-2 to the delivered, or levelized cost of energy (LCOE), as discussed in Section 4.2.3. These are calculated using assumptions about O&M expenses, inverter efficiencies, and derate factors from DOE (2010). Moreover, Figure 4-10 represents LCOEs with no investment tax credit (ITC) for residential systems and only the permanent 10% ITC and 5-year MACRS for commercial and utility systems (since the 30% residential and non-residential ITCs are scheduled to expire after 2016). No state, utility or local incentives are factored into the LCOE. Lastly, we use a number of locations (Phoenix, Kansas City and New York), system orientations and financing conditions to represent a range of PV LCOEs (DOE 2010).

As illustrated in Figure 4-10, residential PV (without the ITC) is broadly competitive with retail electricity rates by 2020, and cheaper than most retail electricity rates by 2030. Commercial PV (with the 10% ITC) is competitive with the higher range of commercial retail electricity rates by 2020 and broadly competitive by 2030. Utility-scale PV (with the 10% ITC) is below the California Market Price Referent (based on the levelized cost of a new combined cycle natural gas turbine facility) by 2020 and broadly competitive with wholesale electricity rates by 2030.

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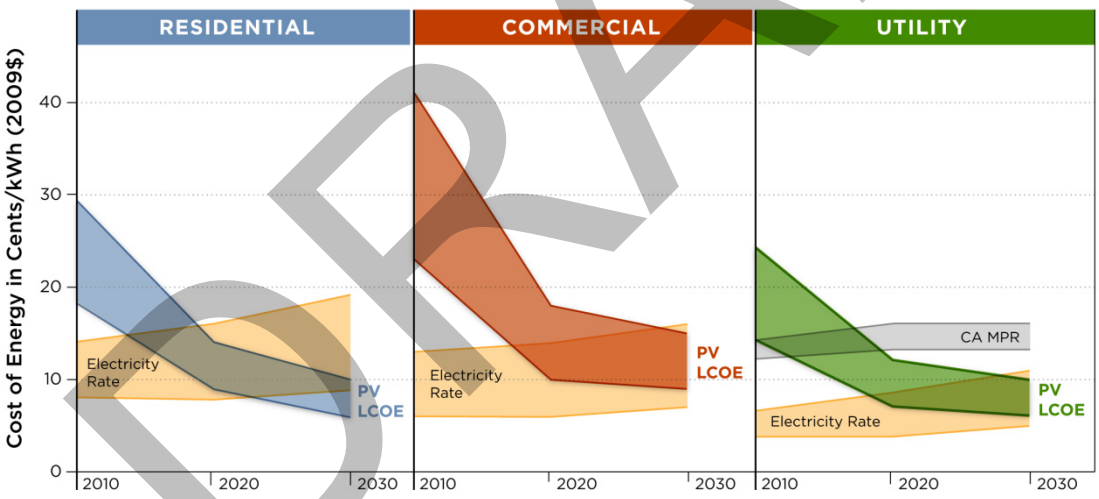
Table 4-2. Installed Costs for Systems with Multicrystalline Modules by Year and Market Segment[9,10]

PV System Component Prices (2009 US$/Wp)	Residential			Commercial			Utility		
	2010	2020	2030	2010	2020	2030	2010	2020	2030
Multicrystalline-Si Module	2.14	1.15	1.03	1.92	1.08	0.98	1.70	1.01	0.92
Inverter	0.51	0.25	0.16	0.40	0.15	0.13	0.36	0.17	0.15
1-axis Tracker	---	---	---	---	---	---	0.48	0.22	0.20
Other Materials	0.51	0.25	0.16	0.73	0.28	0.24	0.31	0.14	0.13
Installation Labor	0.66	0.32	0.20	0.67	0.26	0.22	0.20	0.09	0.08
Permitting & System Design	0.53	0.26	0.16	0.33	0.13	0.11	0.21	0.10	0.09
Installer Overhead & Other	1.60	0.78	0.49	1.05	0.40	0.34	0.80	0.37	0.33
Installed System Cost	**$5.95**	**$3.00**	**$2.20**	**$5.10**	**$2.30**	**$2.00**	**$4.06**	**$2.10**	**$1.90**

Figure 4-10. PV LCOEs by Year and Market Segment[11,12]



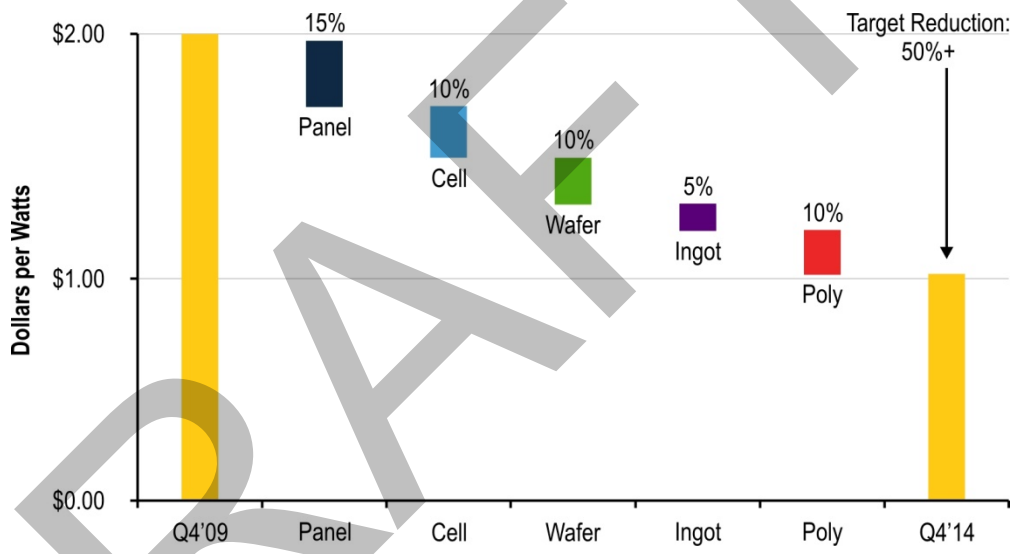
[9] Module costs are from Figure 11, with the assumptions that residential customers would pay the entire module margin, commercial customers would pay half of the module margin, and utility customers would not pay any module margin.
[10] Non-module costs for 2010 are from DOE (2010). Projections assume that all non-module costs decline in equal proportion.
[11] Note that commercial systems assume third-party ownership, and thus the LCOE includes the taxes paid on electricity generated. The same is true for utility systems, but not for residential systems.
[12] The electricity rate range represents one standard deviation below and above the mean U.S. electricity prices for the respective market segment (residential, utility, wholesale). The CA MPR includes adjustments by utility for the time of delivery profile of solar.

4.3.7 INDUSTRY ROADMAPS

The roadmaps of two leading U.S. PV companies offer another perspective on the near-term potential for manufacturing cost reductions. In 2009, SunPower and First Solar published technical roadmaps for module manufacturing cost reductions through 2014. First Solar also produced a roadmap for reducing BOS costs.

SunPower's roadmap is shown in Figure 4-11. SunPower projects that it can reduce its monocrystalline silicon module manufacturing costs from roughly $2/W in the fourth quarter of 2009 to $1/W in 2014.

Figure 4-11. SunPower's Roadmap for Decreasing Monocrystalline Silicon Module Manufacturing Costs from $2/W to $1/W (2009)



First Solar projects reducing its CdTe module manufacturing costs from $0.93/W during the first quarter in 2009 to $0.52–$0.63/W in 2014 (Figure 4-12). Potential cost-reduction strategies include increased module efficiency, increased line throughput, more production in low-cost locations, increased plant scale, and continued R&D investment.

Large PV module manufacturers are working to decrease BOS costs as well, which will ultimately lead to a system cost reduction for all technologies. For example, First Solar is targeting a 30%–35% cost reduction over the next 5 years, primarily by increasing inverter and wiring efficiency and reducing the cost of installation, mounting hardware, engineering, and project management (Figure 4-13).

Combining the mid-range of First Solar's projected module ($0.57/W) and BOS ($0.95/W) cost with a 30% module margin and a 13% system integrator margin yields a total installed price for a large, nontracking system of a little more than $2/W in 2014. Since SunPower does not publish BOS cost projections, we use our BOS model to obtain a 2014 monocrystalline system price of approximately $2.9/W (assumptions are summarized in Table 4-3). The resulting 2014 roadmap-based costs are more aggressive than the cost estimates in Table 4-2, suggesting that even if

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Figure 4-12. First Solar's Roadmap for Decreasing CdTe Module Costs to $0.52–$0.63/W (2009)

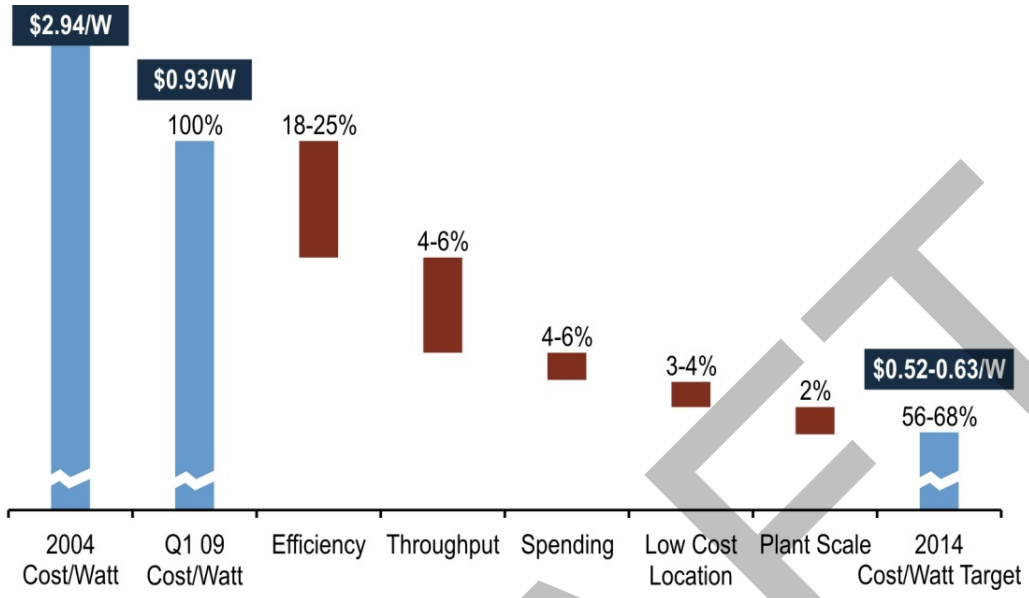
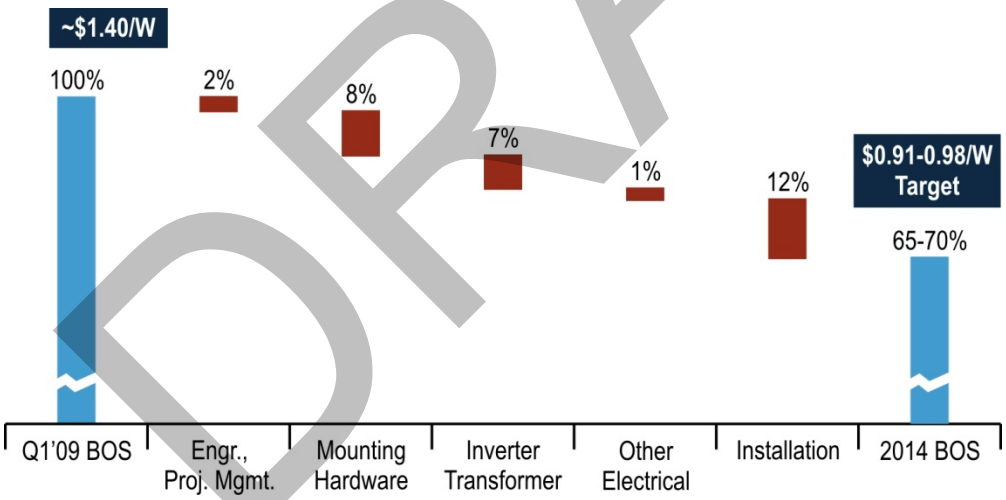


Figure 4-13. First Solar's Roadmap for Decreasing BOS Costs (2009)



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these companies fall short of their targets, they are still on track to reaching PV LCOEs in line with those shown in Figure 4-10.

4.3.8 Research and Development

The potential for PV to achieve the Vision goals assumes no additional material- or system-level breakthroughs. However, continued R&D is assumed and is essential to produce the necessary improvements in performance, cost, reliability, and manufacturing scale.

Table 4-3. Corporate Roadmaps to 2014

	CdTe (First Solar, Nontracking)	Monocrystalline Silicon (SunPower, 1-Axis Tracking)
Module Efficiency (estimated)	13%	22%
Module Cost ($/W)	$0.57	$1
Module Margin, 30% ($/W)	$0.25	$0.43
BOS Cost ($/W)	$0.95	$1.06 (w/tracker)
Integrator Margin, 13% ($/W)	$0.26	$0.37
Total System Price, 2014 ($/W)	**$2.03**	**$2.86**

The Foundation

A robust near-term PV R&D plan is needed to support the many stages leading to commercialization: prototype development, product and process development, measurement and characterization, technology evaluation, and demonstration-system deployment. A substantial base of scientific knowledge exists for crystalline silicon PV technologies, largely owing to computer chip R&D, but such a base is still being built for other leading PV technologies. This is true for all aspects of PV: materials, interfaces, processes for making and altering PV devices, advanced PV device layers, device scale-up from square inches to square meters, and process scale-up to square miles of annual output at high yield. Challenges include maintaining or improving device efficiency, device stability, and process stability.

Interfaces

Many of the most critical issues of PV device performance and reliability occur at interfaces such as the device junction, back contact, front contact, and between various additional layers (e.g., light and carrier reflectors) that modify device behavior. Examples of critical interface behavior include the following:

- Recombination of free carriers within the junction region of high-efficiency PV devices
- Poor, non-ohmic contacting and instability to high-work function, resistive p-type material such as CdTe
- The physics, chemistry, and stability of grain boundaries in multicrystalline semiconductors
- The adherence and lifetime of semiconductor/encapsulant and thermal interface materials
- The numerous interfaces resulting from the use of different materials that respond to different parts of the spectrum in multijunction cells

There is a need for fundamental insights about the interfaces of a PV cell and packaging. Although most work to date has been empirical, there is an opportunity to use more sophisticated R&D tools and expertise to better understand the optical, electrical, mechanical, and chemical properties of these interfaces.

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Performance of Large-Area PV

Sophisticated computational models, tools, and analysis could assist in the correlation of processing parameters with fundamental device physics to accelerate research and commercial product development. One opportunity for existing silicon- and thin film–based modules is the further exploration of material parameter space for optimizing electronic and optical properties. Another is the development and employment of in situ process controls and inline diagnostics for improved manufacturing yield.

Degradation Science

An improved understanding of degradation mechanisms in devices and protective materials would increase module lifetimes and further lower PV's LCOE. It is important to increase understanding of the following areas:

- Photochemical degradation
- Dielectric breakdown
- Leakage current in the presence of water and oxygen
- Impurity diffusion processes in semiconductors and through interfaces, especially in large-area devices (which have inevitable compositional variations in all dimensions)

Well-designed stress tests are needed to define and test potential degradation mechanisms, as are parallel accelerated lifetime models that correlate these new tests with actual outdoor performance over many decades.

Long-Term, High-Potential R&D

Funding for universities, companies, and national laboratories for R&D on non-traditional, high-potential PV technologies promotes innovation and the development and expansion of future PV options. These pre-commercial programs also expand the pool of scientists and engineers with PV expertise.

The PV research community is exploring a portfolio of promising new materials, primarily in the category of abundant, non-toxic, easily processed inorganic semiconductors for direct bandgap thin film cells. Wadia et al. (2009) highlighted these novel R&D efforts. Subsequent to this study, there has been renewed interest among the basic science community to explore underdeveloped materials for PV (e.g., metal oxides and metal sulfides for new PV absorbers). Such long-term efforts build on lessons learned from developing the existing, successful direct-bandgap inorganic thin films and could open up new avenues for low cost while avoiding issues of materials availability.

Beyond new materials, there are new PV device concepts that could improve power conversion efficiency and reduce costs. Of these, the most developed are organic, nanoparticle, and dye-sensitized cells, which are in early stages of commercial development (see Section 4.2.2). They offer the potential for lower costs through use of less-expensive materials and simpler processing. However, there are challenges in attaining high efficiency and long-term reliability.

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4.4 MATERIALS AND MANUFACTURING RESOURCES

The 20% Vision goal assumes that U.S. PV installations will reach about 220 GW in 2030, requiring the PV industry to achieve rapid, large-scale expansion of its raw material supply and manufacturing capacity. If the rest of the world were to follow this same growth trajectory, about 1,100 GW might be installed worldwide, with the actual output in 2030 being about 115 GW/year. This section discusses these expansion challenges.

4.4.1 RAW MATERIALS REQUIREMENTS

Raw material availability can become a concern when there is a supply/demand mismatch or a material shortage. These two conditions are discussed below.

Supply/Demand Mismatch

A supply/demand mismatch is a temporary market imbalance resulting in a shortage of available material due to a lack of extraction, refining, or source-formation capacity, despite a basic accessibility of the underlying material. An example of this type of mismatch in the PV sector is the recent shortage of polysilicon feedstock, which occurred because demand for polysilicon-based modules rose more rapidly than polysilicon production capacity.

Although the polysilicon shortage has dissipated during the past couple of years, it is useful to examine its causes. The delay between perceiving the opportunity and increasing polysilicon production resulted from the time and expense required to build and start up a new polysilicon plant. From initiating plant construction to beginning production takes 2–3 years and costs hundreds of millions of dollars. This constraint on response time was further exacerbated by the lack of vertical integration in the industry, since cell manufactures had to wait for producers to respond to the market signals of increased demand. Lower capital cost processes (e.g., the use of thinner silicon wafers and use of less-refined, solar-grade silicon) will help mitigate this type of imbalance in the future.

Such a temporary supply/demand mismatch is familiar from other industries and is likely to remain a part of the PV landscape as it evolves. Better planning and increased vertical integration can help to minimize these types of disruptions, but cannot completely eliminate them in the future.

Material Shortage

A more serious challenge is a fundamental shortage of material supply. For example, a shortage can occur when not enough material is being mined, or could be mined economically, or when competing uses can afford much higher prices for the material and thus lock up all available supply. Long before the supply is truly inaccessible, prices can rise to uncompetitive levels, which frequently stimulate new sources of supply, balancing demand at a sustainable level.

Material shortages are a concern for the semiconductor materials in some PV technologies: tellurium used in CdTe; indium, selenium, and gallium used in CIGS and some III-V multijunction cells; germanium frequently used in a-Si; and

DRAFT

ruthenium sometimes used in dye-sensitized PV cells. Conductive materials may also be a concern in the longer term, including copper used in all PV wiring, silver used for crystalline silicon PV contacts, and molybdenum used for CIGS PV contacts. Of these, the primary concerns are tellurium for CdTe and indium for CIGS.

About 1,500 MT/yr of tellurium are available from extracted copper, but only about 500 MT/yr are refined owing to a lack of demand. The amount of tellurium available will increase with increasing copper extraction, the demand for which has recently grown by 1%–3% per year. Also, the amount of tellurium recovered from copper mining will increase as tellurium demand increases. Tellurium's major use is as an alloy additive in steel and copper, neither of which is expected to increase significantly with PV demand. About one fifth of the tellurium supply is used in CdTe PV production.

Indium is a relatively rare byproduct of zinc refining. Nearly all of the indium supply is used in thin film coatings, such as those on flat panel liquid crystal displays. Additionally, the use of indium for indium-tin-oxide (a transparent conductive oxide) could limit a-Si; however, using a different conductive oxide such as zinc oxide (ZnO) would alleviate this materials constraint. Germanium used in a-Si bottom cells is an issue but easily replaced by using un-alloyed microcrystalline silicon instead. CPV modules also frequently use rare indium and gallium materials but do not face the same limitations as other technologies. Optical concentration reduces the active semiconductor area required (and thus the rare materials required) by a factor equivalent to the concentration ratio. Also, rare materials are more affordable on a per watt basis which may lead to displacing competing applications or incentivize increased extraction of material resources.

Although crystalline silicon feedstock materials are virtually unlimited, the silver used for contacts has some limitations. However, if a different material is used for contacts, the supply is virtually unlimited. The glass, steel, and aluminum used as encapsulation and support structures are not subject to rigid supply constraints, but their costs will be tied to changing commodity prices.

There are four main ways to ease material constraints:

- Increase efficiency (less material per delivered watt)
- Reduce material use through thinner layers for PV devices
- Improve process utilization and in-process recycling
- Increase ore extraction and refining

Because CdTe and CIGS have basic limits without improvements, these are critical strategies for these technologies. The best CdTe module efficiencies are about 11%, layers are about 3 microns thick, and there are 10 g/m^2 of tellurium in a 3-micron CdTe layer. Combined with 90% process material use (with in-process recycling), this implies that 100 MT of tellurium are needed per GW. If CdTe module efficiency increased to 15% and layer thickness decreased to a little less than 2/3 of a micron (about what is needed to absorb the solar spectrum), tellurium requirements would drop to 13 MT per GW. Copper extraction is increasing 1%–3% per year, which

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implies that tellurium availability in 2030 could increase to about 1,800–2,700 MT/yr. At 13 MT/GW, this implies possible production of 140-200 GW/yr in 2030.

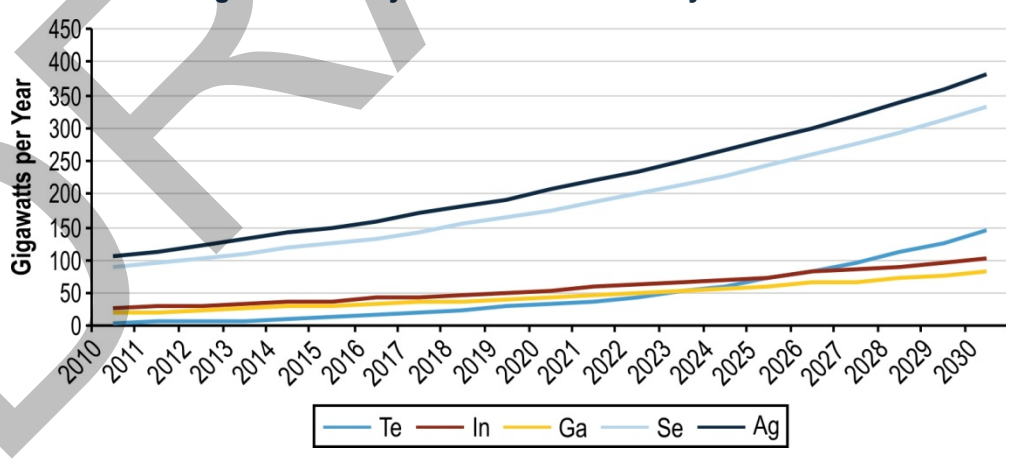
Table 4-4 shows how material use can be reduced with improved efficiency and reduced thicknesses for each material.

Table 4-4. Possible Materials Needed in 2030 per GW of Newly Installed Systems if Material-Reduction Strategies are Successful

Material	PV Type	MT/GW (2010)	MT/GW (2030)
Tellurium (Te)	CdTe	100	13
Indium (In)	CIGS, multijunction	30	9.4
Gallium (Ga)	CIGS, multijunction	8	2.3
Molybdenum (Mo)	CIGS	100	30
Selenium (Se)	CIGS, multijunction	30	16
Silver (Ag)	crystalline Silicon	200	70

Figure 4-14 shows the annual module production limits for several materials calculated using the materials use assumptions in Table 4-4, and a 1% annual growth in extractions. The Vision scenarios could lead to 115 GW/yr of PV demand globally by 2030, and most of these materials appear capable of approximating that amount.

Figure 4-14. Key PV Material Availability Forecast



4.4.2 Manufacturing Scale-up

The PV industry is expanding its manufacturing capacity, helped by new market entrants bringing capital as well as technology, manufacturing, and supply chain management experience, often from other successful industries (e.g., computer semiconductor, liquid crystal display, and specialized material industries). Annual production capacity of PV manufacturing lines has increased from tens to hundreds of MW over the past decade.

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The challenge of scaling-up manufacturing capacity will not limit PV deployment. Global PV manufacturing capacity could be on track to grow from 3.2 GW/year in 2007 to 23.7 GW/year by 2012, based on existing and planned investment (Mehta and Bradford 2009). Peak annual PV deployment reaches 23 GW/year by 2030 in the 20% Vision scenario. The scale up of global PV manufacturing to achieve Vision trends in the U.S., and similar growth targets globally, are not out of line with recent manufacturing growth trends. The capital required to build a 1-GW/year PV manufacturing facility has been estimated at $1–$3 billion (2009 U.S. dollars) (Mehta and Bradford 2009), although recent progress (e.g., First Solar) is pushing this number below $1/W. Neither the cost of building new PV manufacturing capacity nor the rate of growth required to reach Vision PV deployment levels are out of line with current trends.

That said, supply chain planning and clear market signals are needed to enable the required scale-up. For an "emerging" technology such as PV, which initially will have above-market prices, strong and consistent government policy support is needed to create initial demand. PV manufacturers must see a clear market-growth pathway before committing the substantial resources needed to scale-up production capacity and output.

4.5 REFERENCES

Department of Energy. 2010. "Solar Energy Technologies Program Cost Targets: 2009 – 2030." In Process.

First Solar, 2010. *Annual Report 2009*. Securities and Exchange Commission, p. 1.

First Solar. 2009. "Analyst/Investor Meeting." Presentation. Las Vegas, NV. June 24, 2009. http://phx.corporate-ir.net/External.File?item=UGFyZW50SUQ9OTE1OHxDaGlsZElEPS0xfFR5cGU9Mw==&t=1

Goodrich, A. 2010. Internal cost model. Golden, CO: National Renewable Energy Laboratory (NREL).

Goodrich, A. and D. Hsu, 2010. *Solar Manufacturing Cost Models*. In preparation. Golden, CO: NREL.

Grama, S. and T. Bradford, 2008. *Thin-Film PV 2.0: Market Outlook through 2012*. Greentech Media, Inc. and the Prometheus Institute.

Kazmerski, L. 2009. Best Research Cell Efficiencies. Golden, CO: NREL. Adapted and expanded from K. Zweibel, NREL,1995.

Luque, A., S. Hegedus, 2003. Handbook of Photovoltaic Science and Engineering, J. Wiley & Sons., p. 1168.

Mehta, S. And T. Bradford. 2009. *PV Technolgoy, Production and Cost, 2009 Forecast*. Greentech Media, Inc. and the Prometheous Institute.

Mints, P. 2009. Palo Alto, CA: Navigant Consulting Photovoltaic Service Program.

Mints, P. 2010. Palo Alto, CA: Navigant Consulting Photovoltaic Service Program.

Shaheen, S.E., D.S. Ginley and G.E. Jabbour, 2005. "Organic-Based Photovoltaics: Toward Low-Cost Power Generation." *MRS Bulletin*, 30, 1, 10-15.

DRAFT

SunPower. 2008. *Smarter Solar: SunPower Panels Generate the Highest Financial Return for Your Solar Investment*. White paper. http://www.bauerpower.com/files/White-Paper.pdf

Trina Solar. 2009. "Q4 2009 Trina earnings call presentation, mixed silicon costs: $1.24/Wp." http://phx.corporate-ir.net/External.File?item=UGFyZW50SUQ9MzcwMTUxfENoaWxkSUQ9MzY2NzA1fFR5cGU9MQ==&t=1

von Roedern, B. 2010. "NREL-internal solar PV module efficiency survey.' Golden, CO: NREL.

Wadia, C., P. Alivisatos, and D.M. Kammen. 2009. Materials Availability rives the Opportunity for Large-Scale Photovoltaics Deployment, *Environ. Sci. Technol. 43,* 2072–2077

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MAILED 12/19/08

PUBLIC UTILITIES COMMISSION OF THE STATE OF CALIFORNIA

ENERGY DIVISION **RESOLUTION E-4214**
December 18, 2008

R E S O L U T I O N

This Resolution formally adopts the 2008 Market Price Referent values for the use in the 2008 Renewable Portfolio Standard solicitations. This Resolution is made on the Commission's own motion.

SUMMARY

2008 Market Price Referent (MPR) values have been calculated for use in the 2008 Renewable Portfolio Standard (RPS) solicitations.

This Resolution formally adopts the 2008 MPR values for use in the 2008 RPS solicitations. This Resolution is made on the Commission's own motion.

Adopted 2008 Market Price Referents[1] (Nominal - dollars/kWh)				
Resource Type	**10-Year**	**15-Year**	**20-Year**	**25-Year**
2009 Baseload MPR	0.10043	0.10537	0.11126	0.11480
2010 Baseload MPR	0.10175	0.10748	0.11390	0.11761
2011 Baseload MPR	0.10400	0.11046	0.11730	0.12110
2012 Baseload MPR	0.10698	0.11405	0.12126	0.12509
2013 Baseload MPR	0.10998	0.11776	0.12527	0.12915
2014 Baseload MPR	0.11278	0.12122	0.12897	0.13290
2015 Baseload MPR	0.11605	0.12503	0.13290	0.13690
2016 Baseload MPR	0.11971	0.12915	0.13706	0.14111
2017 Baseload MPR	0.12367	0.13352	0.14144	0.14549
2018 Baseload MPR	0.12802	0.13814	0.14603	0.15001
2019 Baseload MPR	0.13271	0.14298	0.15080	0.15464
2020 Baseload MPR	0.13776	0.14797	0.15578	0.15937

[1] Note: using 2009 as the base year, Staff calculates MPRs for 2009-2020 that reflect different project online dates. The 2008 MPR model is available at: http://www.ethree.com/MPR.html

BACKGROUND

The RPS Program requires each utility to increase the amount of renewable energy in its portfolio

The California Renewables Portfolio Standard (RPS) Program was established by Senate Bill 1078 (Chapter 516, statutes of 2002, effective January 1, 2003) and codified at California Public Utilities Code Section 399.11, et seq. The statute requires that RPS-obligated investor-owned utilities (IOU), energy service providers (ESP) and community choice aggregators (CCA) meet annual targets by increasing procurement of Eligible Renewable Energy Resources (ERR) by at least 1 percent of annual retail sales per year until 20 percent is reached, subject to the Commission's rules on flexible compliance, no later than 2017.

The State's Energy Action Plan (EAP) called for acceleration of this RPS goal to reach 20 percent by 2010[2]. This was reiterated again in the Order Instituting Rulemaking (R.04-04-026) [3] issued on April 28, 2004, which encouraged the utilities to procure cost-effective renewable generation in excess of their RPS annual procurement targets[4] (APTs), in order to make progress towards the goal expressed in the EAP. On September 26, 2006, Governor Schwarzenegger signed Senate Bill (SB) 107[5], which officially accelerated the State's RPS targets to 20 percent by 2010, subject to the Commission's rules on flexible compliance.[6] California's renewables goal was furthered on November 17, 2008 when Governor Schwarzenegger signed Executive Order S-14-08, which established a 33 percent RPS goal by 2020.[7]

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[2] The Energy Action Plan was jointly adopted by the Commission, the California Energy Resources Conservation and Development Commission (CEC) and the California Power Authority (CPA). The Commission adopted the EAP on May 8, 2003.

[3] http://www.cpuc.ca.gov/Published/Final_decision/36206.htm

[4] APT - An LSE's APT for a given year is the amount of renewable generation an LSE must procure in order to meet the statutory requirement that it increase its total eligible renewable procurement by at least 1% of retail sales per year.

[5] SB 107, Chapter 464, Statutes of 2006

[6] Sec. 399.14(a)(2)(C)

[7] http://gov.ca.gov/index.php?/executive-order/11072/

MPR is an important element in the RPS procurement process

The MPR is a key component of the RPS program. Pursuant to Legislation, the MPR has three functions.[8] The first, expressed in § 399.14(g), is to deem reasonable per se and allow to be recovered in rates those "[p]rocurement and administrative costs associated with long-term contracts entered into by an electrical corporation for eligible renewable energy resources pursuant to this article, at or below the market price determined by the commission pursuant to subdivision (c) of Section 399.15. . ." The second function of the MPR is to establish the basis for the use of Above-Market Funds (AMFs) which are awarded by the Commission pursuant to SB 1036, Statutes 2007, ch. 685.[9, 10] The third function of the MPR is to set limits on the procurement obligations of retail sellers under the RPS program.[11] That is, if the amount of AMFs available to an electrical corporation is insufficient to support the total costs expended above the market price, then the Commission shall allow an electrical corporation to limit its annual procurement obligation to the quantity of eligible renewable energy resources that can be procured with available AMFs.

To establish the market price necessary for implementation of the RPS program, the Legislature directed the Commission, in consultation with the Energy Commission, to:[12]

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[8] The RPS legislation is codified at Pub. Util. Code §§ 399.11-399.20.

[9] The original method for funding above-market costs was the use of Supplemental Energy Payments (SEPs), administered by the CEC. See §§ 399.13(c), 399.15(b)(5). The SEP program was eliminated by SB 1036 (Perata), Stats. 2007, ch. 685. The existing funds were refunded to the three large IOUs (PG&E, SDG&E, and SCE) and, along with the portion of funds which would have been collected through January 1, 2012, will be used to fund above-market costs of their long-term RPS contracts. See Res. E-4160 (April 10, 2008).

[10] In order to carry out this function, D.04-06-015 concluded that the contract price should be compared to the MPR on a net present value basis as calculated over the entire contract term.

[11] §399.15(d)(3)

[12] §399.15(c)

> Establish a methodology to determine the market price of electricity for terms corresponding to the length of contracts with renewable generators, in consideration of the following:
>
> > (1) The long-term market price of electricity for fixed price contracts, determined pursuant to the electrical corporation's general procurement activities as authorized by the Commission.
> >
> > (2) The long-term ownership, operating, and fixed-price fuel costs associated with fixed-price electricity from new generating facilities.
> >
> > (3) The value of different products, including baseload, peaking, and as-available output.

In D.03-06-071, the Commission determined that it was not feasible to employ the first consideration set out in § 399.15(c), "the long-term market price of electricity for fixed price contracts, determined pursuant to the electrical corporation's general procurement activities." Because the existing long-term contracts for electricity were almost exclusively those signed by the Department of Water Resources (DWR) pursuant to Water Code § 80100 et seq., the Commission concluded that there were not a sufficient number of existing, reasonably-priced, long-term power contracts of recent vintage currently in the utilities' resource portfolios to establish an MPR based on the first consideration. The Commission, in D.03-06-071, therefore relied on the second and third considerations, developing a proxy plant to model the long-term costs "associated with fixed-price electricity from new generating facilities," taking into account "the value of different products, including baseload, peaking, and as-available output."

MPR procedural history

The Commission set the initial parameters for the MPR in D.03-06-071. The method for calculating the MPR was first developed in D.04 06-015. In D.04-06-015, the Commission clarified "what the MPR is not: it does not represent the cost, capacity or output profile of a specific type of renewable generation technology. . . [T]he MPR is to represent the presumptive cost of electricity from a non-renewable energy source, which this Commission, in D.03-06-071, held to be a natural gas-fired baseload or peaker plant." (D.04-06-015, mimeo., p. 6, n.10.)

In D.05-12-042, the methodology for calculating the MPR was expanded and stabilized. This methodology has been used for the resolutions implementing the MPR for 2005 and 2006. The 2007 MPR was calculated pursuant to D.07-09-024, wherein the Commission adopted an interim method to account for the costs of the emission of greenhouse gases (GHG adder).

D.07-09-024 authorized the use of the GHG adder for the 2007 MPR only. That decision also authorized an examination of the MPR for 2008 and later years, to determine whether any changes should be made to the MPR methodology, including how the compliance costs of State mandates to reduce GHG emissions should be reflected in the MPR.

MPR methodology was reevaluated in 2008

The 2008 review process[13] began with comments filed on March 6, 2008 in response to the Administrative Law Judge's (ALJ's) February 8, 2008, Ruling requesting pre-workshop comments on the 2008 MPR. On March 27, 2008, Energy Division staff (Staff) held a workshop where parties discussed potential modifications to the MPR methodology, inputs, and assumptions for 2008 and later years. Parties identified several key issues for review:

- Capacity Factor
- MPR Gas Methodology
- GHG Adder
- Installed Capital Costs and Cost Escalation
- Generation Meter Multiplier (Transmission Line Losses)
- MPR Contract Length

A May 20, 2008 Ruling requested post-workshop comments, which were filed on June 6, 2008; reply comments were filed on June 18, 2008. Parties' comments and reply comments, including pre-workshop comments and presentations made at the March 27, 2008 workshop, informed D.08-10-026, the Commission's 2008 Decision on the Market Price Referent for the California Renewables Portfolio

[13] The following parties participated in the 2008 MPR proceeding: California Wind Energy Association (CalWEA), California Cogeneration Council, Concentrated Solar Power Companies, Large-scale Solar Association, and Solar Alliance, jointly (collectively, CalWEA); Center for Energy Efficiency and Renewable Technologies (CEERT); Central California Power (CCP); Energy Producers and Users Coalition (EPUC) and Cogeneration Association of California, jointly (collectively, EPUC); Green Power Institute (GPI); GreenVolts, Cleantech America, and Community Environmental Council, jointly; Shell Energy North America (US), L.P (Shell); Division of Ratepayer Advocates (DRA); Pacific Gas and Electric Company (PG&E); San Diego Gas & Electric Company (SDG&E); Southern California Edison Company (SCE); The Utility Reform Network (TURN); and Union of Concerned Scientists (UCS).

Standard. D.08-10-026 refined the MPR in matters related to the methodology; additionally, several issues were determined to be within the discretion of Staff. Accordingly, we discuss those changes in this Resolution.

MPRs were calculated using a cash-flow simulation methodology

The 2008 MPRs were calculated using the "MPR model", which is based on a cash-flow simulation methodology approved by the Commission.[14] The MPR model requires several types of input data, including natural gas prices, capital costs, operating costs, finance costs, taxes, and power delivery assumptions. The primary input drivers for the MPR calculation are the California (CA) gas price forecast, power plant capital costs, and the capacity factor for a proxy baseload plant. (Refer to 2008 MPR model, tabs; CA_Gas_Forecast, Install_Cap, and CF_Inputs.)

The MPR model calculates what it would cost to own and operate a baseload combined cycle gas turbine (CCGT) power plant over a 10, 15, 20 and 25-year period. The cost of electricity generated by such a power plant, at an assumed technical capacity factor and set of costs, is the proxy for the long-term market price of electricity. To ensure that the MPR represents "the value of different products including baseload, peaking, and as-available output,"[15] the IOUs apply their IOU-specific Time of Delivery (TOD)[16] profiles to the baseload MPR when evaluating RPS renewable facilities. The application of TOD factors to the MPR result in a market price for each product and electric generating unit. (Refer to 2008 MPR model "CF_Data Set" and "Control" tabs.)

Release of 2008 MPR is consistent with prior Commission decisions

Pursuant to D.05-12-042, Staff is required to prepare a draft resolution for the annual MPR, including any relevant supporting materials as attachments to the draft resolution. The draft resolution will be released after all utility solicitations have closed.[17] For 2008, the draft resolution incorporates the methodological

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[14] A list of all relevant MPR documents, with links, is provided at the beginning of this resolution's Discussion section.

[15] Sec. 399.15(c)(3).

[16] TOD factors are based on the forward value of electricity during different TOD periods.

[17] The three large California utilities submitted their letters to the Executive Director notifying the Commission that their solicitations were closed on: Pacific Gas & Electric–

changes adopted in the Commission's recent decision D.08-10-026 and refines several MPR inputs at the recommendation of Staff, as discussed herein. Parties will have the usual opportunity to file comments and reply comments on the draft resolution prior to its formal consideration by the Commission.[18]

DISCUSSION

Please refer to the following documents in the following chronological order for a detailed discussion of the MPR methodology:

- **D.04-06-015**: Opinion Adopting Market Price Referent Methodology http://www.cpuc.ca.gov/word_pdf/FINAL_DECISION/37383.doc
- **Resolution E-3942**: Adopts 2004 MPR Values for 2004 RPS Solicitation http://www.cpuc.ca.gov/WORD_PDF/FINAL_RESOLUTION/48242.DOC
- **D.05-12-042**: Interim Opinion Adopting Methodology for 2005 Market Price Referent http://www.cpuc.ca.gov/WORD_PDF/FINAL_DECISION/52178.DOC
- **Resolution E-3980**: Adopts 2005 MPR Values for 2005 RPS Solicitation http://www.cpuc.ca.gov/WORD_PDF/FINAL_RESOLUTION/55465.DOC
- **Resolution E-4049**: Adopts 2006 MPR Values for 2006 RPS Solicitation http://www.cpuc.ca.gov/word_pdf/FINAL_RESOLUTION/63132.doc
- **D.07-09-024**: Opinion on Petition for Modification of Decision 05-12-042 http://docs.cpuc.ca.gov/WORD_PDF/FINAL_DECISION/73031.DOC
- **Resolution E-4118**: Adopts 2007 MPR Values for 2007 RPS Solicitation http://docs.cpuc.ca.gov/word_pdf/FINAL_RESOLUTION/73594.doc
- **D.08-10-026**: Decision on Market Price Referent for the California Renewables Portfolio Standard http://docs.cpuc.ca.gov/PUBLISHED/FINAL_DECISION/92445.htm

The 2008 MPRs are calculated pursuant to D.08-10-026

In D.08-10-026, the Commission modified the MPR methodology and broadly examined the MPR model inputs. In this section we discuss modifications to the MPR model by Commission decision as implemented by Staff.

May 13, 2008, Southern California Electric– May 5, 2008 and San Diego Gas & Electric– April 30, 2008.

[18] D.04-06-015 (Footnote 21, p.30)

To facilitate party review of 2008 MPR modifications, the 2008 MPR model includes toggle switches or lists on the "Control" tab that allows parties to evaluate MPR values while applying 2007 and/or 2008 inputs.

2008 MPR Gas Methodology and Inputs

The most significant cost during the life a new CCGT is the cost of its natural gas fuel. The MPR models the cost of gas over the entire life of the proxy plant's long-term contract. As the Commission pointed out in D.05-12-042, no new gas-fired plant in California actually enters into a 20-year fixed price contract for physical gas delivery. Therefore, in order to capture the "fixed-price fuel costs associated with fixed-price electricity from new generating facilities," the MPR model creates a forecast of long-term gas prices for purposes of the MPR. As explained in D.05-12-042, the MPR model is based on the fact that California market participants , when considering a power purchase agreement (PPA), "use some mixture of market data (NYMEX prices) and fundamentals forecasts for estimating long-term gas prices in a variety of settings, not only new PPAs for electricity produced from CCGTs".[19]

New York Mercantile Exchange (NYMEX) data

In D.05-12-042, the Commission authorized Staff to use all available NYMEX forward contract data, under this guidance, the 2005, 2006 and 2007 MPRs were calculated using the full six years of NYMEX. In 2008, NYMEX extended its forward gas contract term offering from six to 12 years.

The Commission weighed the pros and cons of extending the MPR methodology to incorporate the additional years of NYMEX data that parties identified in their comments. Specifically, CAlWEA, UCS and PG&E supported the MPRs' continued preference for market data, i.e., full 12 years,[20] while TURN, SCE and SDG&E opposed the use of 12 years NYMEX based on concern about relying on

[19] D.05-12-042, p. 17.

[20] D.05-12-042 adopted five Guiding Principles for the MPR Gas Methodology: 1) The natural gas prices used to calculate the MPR should reflect the behavior of market participants, 2) Market data should be used to the extent possible, 3) For shorter-term contracts, forecast data should be verified against forward market data; for longer-term contracts that extend beyond available market data, forecasts should be benchmarked against fundamental costs and/or historical market data, 4) The methodology should be consistent with the evaluation of other products and 5) The methodology should be consistent with previous regulatory decision.

the outer years of NYMEX data where minimal or no actual trades had occurred. SCE supported its position stating that for its own operations, they do not enter into NYMEX transactions so far into the future.[21] From a procurement perspective, the opposing parties concerns have merit. In D.08-10-026, however, the Commission highlighted an important distinction about the MPR. That is, "…that gas forecast information for the MPR is part of a modeling exercise, not a procurement transaction".

Thus, D.08-10-026 authorized Staff to use between nine and 12 years (the current maximum) of NYMEX forward price data. In reviewing the applicable NYMEX data set,[22] Staff determined that there was no evidence of a single outlier that would argue for using less than all available NYMEX forward prices. (Refer to 2008 model, "NYMEX_Futures" and "CA_Gas_Forecast" tabs.)

Transition to Fundamental Forecast

The MPR model's long-term gas contract requires the use of fundamental gas forecasts to project gas prices when NYMEX forward prices are not available. The MPR fundamental forecast for years 12 – 25 was developed using three out of four private sector natural gas forecasts (Henry Hub) from Cambridge Energy Research Associates, PIRA Energy Group, Global Insight or Wood Mackenzie. Due to contractual obligations requiring the Commission to keep the forecast confidential, Staff can not reveal which of the four firms the forecasts were purchased from.

The use of fundamental forecasts requires a two-step implementation process. First, a methodology must determine how to utilize the fundamental forecast data, and secondly, a methodology is required to transition from NYMEX data to fundamentals data.

For 2007, the transition between NYMEX forward prices and the MPR fundamental forecast was accomplished by making a straight line interpolation between the last year of NYMEX data (year 2012) and the MPR fundamental

[21] SCE, post-workshop reply comments, p. 13.

[22] The MPR Gas Methodology uses a 22-trading day average of NYMEX forward prices ending with the close of the utilities' solicitations. Accordingly, the 2008 MPR Gas Methodology is derived based on the 22-trading day average of NYMEX forward prices leading up to May 13, 2008.

forecast's year 2016 value to create prices for years 2013, 2014 and 2015. (Refer to 2007 MPR model, "CA_Gas_Forecast" tab.)

D.08-10-026 ordered Staff to continue the use of private fundamental forecasts; however, the methodology now utilizes the annual percentage rate change, rather than the actual values, *per se,* to produce the MPR fundamental forecast. D.08-10-026 also directed Staff to make the transition from NYMEX forward prices to the first year of the MPR fundamental forecast by using a linear trend of the last three to five years of NYMEX forward prices, which mitigates the impact of any one price in the outer years of NYMEX. The first year of the MPR fundamental forecast is then extended using the annual escalation rate for the remainder of the MPR fundamental forecast. (Refer to Appendix C for the 2008 California and Henry Hub gas forecasts (2009 – 2050) and Appendix D for specific inputs used in the 2008 gas forecast.)

California Basis Adjustment

The 2007 MPR used NYMEX Clearport futures data to account for the cost of delivery from Henry Hub to California.[23] Staff averaged PG&E Citygate and SoCal Border Clearport prices for the three years of available data and then fixed the average price in year three for all years throughout the proxy CCGT's contract term.

D.08-10-026 ordered Staff to retain the use of NYMEX Clearport prices for years when NYMEX data is used, but now requires that California Basis data from private fundamental forecasts be used when the MPR Gas Methodology relies on fundamental forecast data. (Refer to 2008 MPR model "CA_Basis_Adj" tab.)

Pursuant to D.08-10-026, Staff continued its use of PG&E Citygate and SoCal Border Clearport prices for the first three years and then fixed the average price in year three through 2020, the last year when the MPR Gas Forecast relies on NYMEX forward prices.[24] The California Basis Adjustment for the remainder of

[23] "The Henry Hub is the largest centralized point for natural gas spot and futures trading in the United States. The New York Mercantile Exchange (NYMEX) uses the Henry Hub as the point of delivery for its natural gas futures contract." http://www.eia.doe.gov/oiaf/analysispaper/henryhub/

[24] NYMEX Clearport provides SoCal prices for up to six years; however, PG&E Citygate is only available for three; therefore, Staff determined it most reasonable to use the same methodology that was used in prior years.

the proxy CCGT's contract term is based on the average of basis prices from the private fundamental forecasts used to develop the long-term California MPR Gas Forecast. (Refer to 2008 MPR model "CA_Basis_Adj" tab.)

2008 MPR Non-Gas Methodology and Inputs

Installed Capital Cost Data Set

D.05-12-042 adopted criteria for conducting a market survey of plant costs and ordered Staff to use installed capital costs that reflect the actual cost of a range of CCGT projects that have been built in the last few years or are currently under construction in California. Specifically, Staff was ordered to use the following as suggested criteria in selecting plants to survey:

- 500 MW CCGT (approximate)
- Utilizes GE "F-Series" turbine
- Located in California

Using the survey criteria outlined above, Staff identified the following plants that had publicly available cost data; Palomar (SDG&E), and Cosumnes (SMUD).[25] The 2007 MPR model's data set for installed capital cost consists of the Palomar and Cosumnes power plants.

D.08-10-026 examined whether the Colusa power plant, which is currently under construction, would meet the criteria for use in the MPR calculation.[26] CalWEA and Shell argued that Colusa represented a distressed sale, and therefore, did not meet the criteria established in D.05-12-042.[27] Ultimately, D.08-10-026 determined that Colusa does meet the MPR criteria, because the reasonableness for Colusa was approved through formal contested Commission proceedings and moreover, the certificate of public convenience and necessity (CPCN) retained the initial cost cap.[28]

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[25] Refer to Resolution E-4049, Appendix C, for a detailed discussion on how the installed capacity cost for the 2006 MPR was developed.

[26] D08-10-026, pp 21-23.

[27] CalWEA, post-workshop comments, pp 3-4; Shell, post-workshop comments, pp 4-5.

[28] D.06-11-048 approved several contracts, including the Colusa plant, which resulted from PG&E's 2004 long-term request for offers; D.08-02-019 granted PG&E's request for a certificate of public convenience and necessity to build the plant itself and reaffirmed Colusa's $684 million cost cap imposed in D.06-11-048.

While D.08-10-026 does not order Staff to incorporate Colusa into the MPR model, based on the decision's findings, Staff determined that the MPR calculation would benefit from adding Colusa to the limited data set for installed capital costs. According to D.08-02-019, the cost to build Colusa is set at $684.4 million, which results in $1,042/kw based on a 2010 operating online date. To incorporate Colusa into the MPR model, Staff de-escalated Colusa's cost cap using USACOE. The adjustment results in overnight installed capital costs of $670.57 million or $1,021/kw. (Refer to 2008 MPR model, "Install_Cap" and "Control" tabs.)

Escalation of Historic Capital Cost

The 2007 MPR model calculated its installed capital cost estimate by applying the annual United States Army Corps of Engineers (USACOE) Construction Cost Index to capital cost data from the Palomar and Consumnes plants.[29]

D.08-10-026 agreed with the majority of parties, that given the MPR model's limited and relatively older data set, combined with a significant increase in power project development costs, that the use of a private index may be warranted, "…to bring the older cost values more into line with 2008 values".[30] D.08-10-026 authorized Staff to determine the most reasonable data source for escalating the MPR model's historic capital costs.

For the 2008 MPR calculation, Staff used Handy-Whitman's Index of Public Utility Construction Costs (Handy-Whitman),[31] which was recommended by several parties,[32] to escalate the historic installed capital costs for Palomar and Consumes. SDG&E described Handy-Whitman's index as an industry standard that has precedent in the utility industry and with regulatory agencies, and is available at a reasonable cost.[33] Applying Handy-Whitman results in

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[29] CWBS Feature Code 07 (Power Plants). Updated March 30, 2007. http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1304/toc.htm

[30] D.08-10-026, pp 23-24.

[31] Whitman, Requardt & Associates, LLP publishes the Handy-Whitman Index of Public Utility Construction Costs. http://www.wrallp.com/

[32] CalWEA, UCS and SDG&E

[33] SDG&E post-workshop reply comments, p. 3.

approximately a 7% increase in the MPR model's installed capital costs.[34, 35] (Refer to 2008 MPR model "Install_Cap" and "Control" tabs.)

Escalation of Current Capital Cost

The 2007 MPR model escalated capital costs through 2010 according to the methodology adopted in D.05-12-042, which assumed that in 2010, increased technical efficiencies would offset incremental capital costs (e.g., inflation).

In D.08-10-026, the Commission determined that, "… the record in this proceeding reveals no reason to believe that the dynamic relationship between cost increases and efficiency improvements will suddenly end in 2010".[36] Accordingly, the MPR methodology was revised to provide for the escalation of installed capital costs on a rolling five-year basis. The 2008 MPR values are calculated assuming that capital costs increase through 2013 and then remain fixed throughout the proxy CCGT contract term. (Refer to 2008 MPR model "CF_Data_Set" tab; cells J13:O13) Installed capital cost will continue to be escalated, prospectively, using the USACOE Index.

Capacity Factor

The 2007 MPRs were calculated using an "economic" capacity factor based on the weighted average of the utility's time of delivery (TOD) factors to determine when it was economic for the proxy CCGT to operate. The 2007 MPR methodology produced an economic capacity factor of approximately 71%.[37]

D.08-10-026 determined that the Commission's statutory obligation was best achieved by calculating MPR values based on a technical capacity factor rather than an economic capacity factor. Specifically, D.08-10-026 found that, "The use of the technical capacity factor eliminates the distortions of the weighted average of TOD factors in the current method [and] …results, when properly time-differentiated, in an MPR that better reflects the values of baseload, peaking, and intermittent products".[38]

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[34] Assumes Palomar, Consumnes and Colusa.

[35] Handy-Whitman's Bulletin 168, July 2008.

[36] D.08-10-026, p. 25.

[37] See 2007 MPR model "Cap_Fac" tab.

[38] D.08-10-026, p. 20

Accordingly, Staff revised the 2008 MPR model so that the proxy CCGT's capacity factor is now based on the proxy plant's technical capacity factor, which is assumed to be 92%. The MPR's capacity factor is now an input on the "CF_Inputs" tab and Staff deleted the "Cap_Fac" tab, which was used expressly for calculating the economic capacity factor.
D.08-10-026 highlighted the necessity that an MPR calculation using a technical capacity factor must be applied to the utility's TODs to ensure that the calculation fully reflects the costs and revenue of the proxy CCGT. That is, the technical capacity derived MPR, when multiplied by the utility's TOD factors, results in the market price. Moreover, applying the utility's TODs is necessary to evaluate RPS bids received in the annual solicitations in order to produce a time-differentiated bid evaluation process. (Refer to Appendix B for review of the utilities TOD periods and factors)

GHG compliance cost

In D.07-09-024, the Commission determined that it was reasonable to include a GHG adder to account for the costs of compliance with recent California climate laws, Assembly Bill (AB) 32 (Statutes 2006, ch. 488 and SB 1368 (Statutes 2006, ch. 598), because the MPR applies to long-term contracts.[39] Pursuant to D.07-09-024,[40] Staff calculated the 2007 MPRs using the $/$CO_2$ ton values and methodology of the Energy and Environmental Economics (E3) Avoided Cost model for calculating a GHG adder.[41] The 2007 MPR model assumed a CO_2 adder of $8/ton for 2004, escalated at 5 percent per year through 2023 and then escalated using a straight line trend of $0.90/ton per year from 2024-2040.

D.08-10-026 revised further the MPR methodology to reflect California's GHG environmental laws. D.08-10-026 made the cost of compliance with GHG

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[39] The Global Warming Solutions Act and Emissions Performance Standard, respectively.

[40] D.07-09-024, Ordering Paragraph 1 states, "The calculation of the 2007 market price referent (MPR) used in the renewables portfolio standard program shall use the model for calculating greenhouse gas emissions costs (GHG adder) developed by Energy and Environmental Economics and adopted in Decision 04-12-048, applied to the MPR's combined cycle combustion turbine proxy plant for GHG emissions costs beginning January 1, 2012. "

[41] The Avoided Cost model developed by E3's was adopted by the Commission in D.04-12-048 (R.04-04-003) and D.05-04-024 (R.04-04-025). The model is available here: http://www.ethree.com/cpuc_avoidedcosts.html

regulation a permanent component of the MPR calculation and because at this time there is no GHG compliance market in California, the decision adopted criteria for Staff to employ in modeling the GHG compliance costs incurred for the MPR proxy CCGT. Specifically, D.08-10-026 identified criteria that Staff must use for selecting a resource for modeling GHG compliance costs for the MPR. The model should be:

- publicly available;
- based on multiple scenarios and sources of information;
- based on realistic and public assessments of policy proposals and scenarios;
- based on the most current reliable information that conforms to the other three criteria.

At the March workshop, Synapse discussed its methodology and explained how it was based on the analysis of multiple state and federal GHG policies, economic models used to determine price impacts, as well as, ranges of CO_2 prices used by utility regulatory commissions and utilities in resource planning.[42] Staff has determined that at this time, the Synapse model best meets the criteria established in D.08-10-026.

The 2008 MPR model uses $/$CO_2$ ton values based on Synapse's most recent report, "Synapse 2008 CO_2 Price Forecasts".[43] Specifically, Staff used the Synapse "mid-case" cost data, which was recommended by CalWEA and UCS.[44] The Synapse report assumes CO_2 prices of $15 in 2013, increasing to $30.80 in 2020 and $53.40 in 2030, which results in a levelized price of $30/ CO_2 ton in 2007$. Staff converted the reports $/$CO_2$ ton values, which are provided in 2007$, to

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[42] Synapse presentation materials are available at: http://www.cpuc.ca.gov/NR/rdonlyres/022569BE-516A-4E13-87D8-733C989D8411/0/MPRGHGadder_2008MPR_workshop_Synapse_UCS.ppt#256,1, Greenhouse Gas Adder for Use in Determining the 2008 MPR

[43] http://www.synapse-energy.com/Downloads/SynapsePaper.2008-07.0.2008-Carbon-Paper.A0020.pdf

[44] CalWEA post-workshop reply comments, p. 10; UCS post-workshop reply comments, p. 5.

nominal$ using a 2.5% inflation rate.[45] (Refer to 2008 MPR model "CF_Data_Set" tab; row 9.) The table below identifies MPR GHG compliance costs for 2012, 2015 and 2020 in short tons and its metric tonne (MT) equivalent.

Year	**2012**	**2015**	**2020**
MPR GHG compliance cost in short tons (nominal$ / CO_2 ton)	**$10.18/ CO_2 ton**	**$23.76/ CO_2 ton**	**$42.46/ CO_2 ton**
Conversion to Metric Ton (nominal$ /MT CO_2)	$11.22/ MT CO_2	$26.19/ MT CO_2	$46.80/ MT CO_2

General Meter Multiplier (Transmission Line Losses)

The 2007 MPR model used a General Meter Multiplier (GMM) of 98.5%, which is equivalent to a 1.5% line loss factor, based on a simple average of CAISO's transmission losses.[46]

D.08-10-026 determined that the MPR methodology should be revised to accommodate the likelihood that a PPA between a California LSE and a CCGT would require delivery at the busbar.[47] Accordingly, the 2008 MPR model calculates MPRs based on delivery at the delivery at the busbar. (Refer to "CF_Inputs" tab; cell E34:E35.)

Capital Cost Inputs

The MPR model requires fixed and variable operational and maintenance (O&M) costs to calculate total installed capital costs for the MPR proxy CCGT. The 2007 MPR calculated average fixed and variable O&M costs based on data from Palomar, Gateway (formerly, Contra Costa), and Mountain View facilities, as well as data from the CEC and Energy Information Agency (EIA).

During the evaluation of the 2008 MPR methodology and inputs, parties were asked to comment on the extent to which the MPR model may benefit from

[45] Staff implemented the Synapse values in consultation with David White, one of the principal authors of the report, "Synapse 2008 CO_2 Price Forecasts Report".

[46] http://oasis.caiso.com/

[47] D.08-10-026, pp 25-26.

either inputs or assumptions from the CEC's Comparative Cost of Generation Model (COG).[48] CalWEA supported the use of the COG's fixed and variable O&M and heat rate values and PG&E stated that the COG's fixed O&M and heat rate assumptions seemed reasonable.[49]

Staff determined that the MPR model should update its fixed and variable O&M costs using the CEC's COG report, which is based on a survey of 19 CCGTs built in California, nine of which began operating as recently as 2005 or 2006.[50] See table below for comparison of 2007 and 2008 MPR fixed and variable O&M data sets. The MPR model's heat rate is based on the turbine employed in the proxy CCGT. Because the 2008 MPR model assumes the same turbine used in calculating the 2007 MPR, the 2008 MPR model's heat rate is unchanged. (Refer to 2008 MPR model "CF_Data_Set" and ""Control" tabs.)

MPR Model Data Set	Fixed O&M	Variable O&M
2007 MPR inputs[51]	$13.28/kw-yr	$2.58/Mwh
2008 MPR inputs	$9.70/kw-yr	$4.36/MWh

MPR Contract Length

The 2007 MPR model calculated MPR values based on 10, 15 and 20-year contracts. In D.08-10-026, the Commission found that, "because parties have negotiated and presented for approval RPS contracts with extended terms, it is

[48] Comparative Cost of California Central Station Electricity Generation Technologies, December 2007. The report is available at: http://www.energy.ca.gov/2007publications/CEC-200-2007-011/CEC-200-2007-011-SF.PDF

[49] Respectively, CalWEA, pre-workshop comments, p. 4; PG&E pre-workshop comments, p. 4

[50] Comparative Cost of California Central Station Electricity Generation Technologies, December 2007, Table 11.

[51] These 2007 MPR input values represent the inputs used for calculating the 2007 MPR, escalated to 2008$ for an equivalent comparison to the COG values in 2008$. The 2007 MPR values also reflect a corrected minor error in the 2007 MPR fixed cost data set.

reasonable to allow staff to calculate the MPR so that such contracts can be evaluated consistently with contracts with more standard lengths".[52]

Pursuant to D.08-10-026, Staff revised the MPR model to allow for MPR calculations for a 25-year contract. (Refer to 2008 MPR model, "Control" tab.)

Miscellaneous 2008 MPR Model Updates

- Dry Cooling Cost Inputs
  - Staff updated the 2008 MPR model's dry cooling cost data based on the CEC's most recent COG report. (Refer to 2008 MPR model, "Install_Cap" tab)
- PG&E Gas Delivery Tariff
  - The 2008 MPR model includes PG&E's Backbone transmission tariff rates for delivery from Malin (redwood) and Topock (Baja) as inputs to the MPR model's average gas distribution rate. Including the average of these tariffs increases the 2008 MPR model's average distribution rate by approximately $0.16/MMBtu. (Refer to 2008 MPR model, "Delivery_Tar" tab, cells D21:D22.)

MPRs are calculated to reflect multiple CCGT online dates

Many renewable projects in California typically take 2 – 5 years to construct and are potentially dependent on major transmission upgrades that will not be completed until 2010 or later. Additionally, recent renewable solicitations have included bids with multiple phase build-outs and options for subsequent projects. Consequently, renewable projects that bid into an RPS solicitation could have commercial online dates as late as 2020. To ensure that there is an appropriate MPR for all of the 2008 RPS projects; Staff has calculated the 2008 MPRs assuming a range of project online dates (2009 – 2020).

COMMENTS

Public Utilities Code section 311(g)(1) provides that this resolution must be served on all parties and subject to at least 30 days public review and comment prior to a vote of the Commission. Section 311(g)(2) provides that this 30-day

[52] D.08-10-026, p. 27.

period may be reduced or waived upon the stipulation of all parties in the proceeding.

The 30-day comment period for the draft of this resolution was neither waived nor reduced. Accordingly, this draft resolution was mailed to parties for comments on November 4, 2008.

On November 24, 2008, timely comments were filed by PG&E, SDG&E, SCE, DRA and CalWEA. Reply comments were filed by CalWEA on December 1, 2008.

Parties' comments generally support the draft resolution. The comments primarily focus on minor modeling errors which we discuss below. Some parties' comments address issues already decided in D.08-10-026 and, thus, are outside the scope of this resolution. All comments and reply comments have been carefully considered.

Modeling of GHG compliance costs

CalWEA commented that the 2008 MPR Model incorrectly calculated the GHG compliance costs for the 2008 MPR. Specifically, CalWEA argued that the phase-in approach recommended in D.08-03-037 should not be used in calculating GHG compliance costs for the 2008 MPR because (1) the phase-in approach fails to account for the generator's opportunity cost of buying and selling allowances, (2) the GHG Decision is unclear on how allowances will be allocated to "new entrant" CCGTs, which is how the MPR is classified, and (3) the phasing in of GHG compliance costs was not considered in the 2008 MPR methodology proceeding. No party filed reply comments opposing CalWEA's position.

The issues raised by CalWEA suggest that the draft resolution may have made a calculation of GHG compliance costs that is more precise than the record and the State's current policy can justify. Because D.08-10-037 is a recommendation to the California Air Resources Board, but is not yet State policy, it will not be relied upon for the purposes of calculating GHG compliance costs as they relate to the 2008 MPR.[53] Accordingly, the 2008 MPR GHG compliance costs will be calculated in the same manner as they were for the 2007 MPR.

[53] The California Air Resources Board is responsible for implementating Assembly Bill 32, the State's emissions reduction policy.

Modeling of the MPR fundamental gas forecast

PG&E identified in its comments a minor error in the MPR Model's fundamental gas forecast calculation. Specifically, PG&E noted that the Model transitioned from NYMEX prices to fundamentals in 2020 rather than in 2021. In their reply comments, CalWEA concurred that this error exists and that it should be corrected.

Staff agrees with the PG&E and CalWEA and has revised the MPR Model accordingly. (Refer to 2008 Model, "CA_Gas_Forecast" tab.)

Cost adjustment made for Colusa

SCE noted in its comments that the MPR Model erroneously made an additional cost adjustment for the Colusa power plant. Specifically, the Model increased the Commission approved cost-cap figure to account for dry-cooling, which SCE contends is already reflected in the cost cap.

Staff confirmed that the cost of building Colusa included dry-cooling and has deleted the cost adjustment for Colusa. (Refer to 2008 Model, "Install_Cap" tab, cells H10:I10.)

Escalation of historic capital costs

SCE argued in its comments that Staff exceeded its authority granted by D.08-10-026 for calculating MPR installed capital costs. SCE requested a change in the Model's calculation. No party supports SCE's position. Furthermore, SCE claimed that Staff did not explain the need or rational for its use of Handy-Whitman rather than USACOE.

We disagree with SCE. In D.08-10-026, this Commission did not revisit or change the technical methodology for calculating MPR installed capital costs. Installed capital costs for the 2008 MPR were calculated in this same manner as they were in past years, with the exception that, pursuant to D.08-10-026, Staff escalated installed capital cost (historic) using Handy-Whitman. Accordingly, we reject SCE's request and reaffirm our decision to use Handy-Whitman

Separately, SCE identified an error in the cost estimate date used for the Consumnes power plant. Specifically, SCE commented that the MPR Model incorrectly identified the cost estimate date for Consumnes as September 2005. SCE contends that the Model should be revised to reflect a March 2006 cost

estimate date based on documentation for the bond issue which is relied on for the cost estimate for Consumnes.

While we agree with SCE that an error exists, we reach a different conclusion for resolving this discrepancy. Further review of Consumnes' bond documentation, which was issued on January 16, 2006, reveals that the cost estimate of $435 million likely accounts for a delay of project's operational date from September 2005 to March 2006. Therefore, Staff changed the cost estimate date for Consumnes from September 2005 to January 2006 the date of the bond issue. (Refer to 2008 Model, "Install_Cap" tab.)

Modeling of MPR for contracts of greater than 20 years

SDG&E identified an error in the MPR Model's calculation for contracts of greater than 20 years. SDG&E noted that the MPR Model improperly excluded fixed costs and tax expenses for contracts longer than 20 years.

SDG&E suggested several changes to formulas in the MPR Model to implement a 25-year MPR. However, SDG&E recommended changes that impact the MPR for contracts of 20 years and less, which should not be the case. CalWEA in its reply comments agrees that the problem exists but offers a more accurate solution which we adopt with a minor modification.

The MPR methodology provides that the proxy CCGT will recover its fixed costs over 20 years regardless of the length of the contract.[54] The fixed costs for shorter term contracts are levelized over the 10 or 15-year contract term. Consistent with the MPR methodology, the 25-year MPR should also recover its fixed costs over 20 years. However, continuing the escalation of fixed revenues beyond the term of debt and depreciation (20 years) results in extremely high taxes for the last five years of the 25-year MPR. While the MPR methodology specifies a 20-year debt term, in reality, it is likely that the PPA would be structured in such a way as to minimize this tax burden. Assuming a 20-year term for debt and depreciation, Staff finds it more reasonable to limit the fixed revenues escalation to the same terms. Therefore, the 25-year MPR's fixed cost recovery will be limited to the ongoing annual fixed costs over the last five years, which are insurance, fixed O&M, collateral and taxes. (Refer to 2008 Model, "Fixed_Comp" tab.)

[54] MPR variable costs are recovered over the length of the contract.

FINDINGS

1. The 2008 MPRs were calculated and released consistent with D.08-10-026 and prior Commission decisions.
2. The 2008 MPR values for baseload proxy plants have been finalized for use in the 2008 Renewables Portfolio Standard (RPS) solicitations.

THEREFORE IT IS ORDERED THAT:

1. The 2008 MPRs in Appendix A are approved for use in the 2008 RPS solicitations.
2. This Resolution is effective today.

I certify that the foregoing resolution was duly introduced, passed and adopted at a conference of the Public Utilities Commission of the State of California held on December 18, 2008; the following Commissioners voting favorably thereon:

/s/ PAUL CLANON
PAUL CLANON
Executive Director

MICHAEL R. PEEVEY
PRESIDENT
DIAN M. GRUENEICH
JOHN A. BOHN
RACHELLE B. CHONG
TIMOTHY ALAN SIMON
Commissioners

APPENDIX A

Adopted 2007 Market Price Referents (Nominal - dollars/kWh)

Operation Date	Baseload MPR	10 year	15 year	20 year	25 year
2009	MPR All-in	**0.10043**	**0.10537**	**0.11126**	**0.11480**
	MPR fixed component	0.02186	0.02262	0.02332	0.02192
	MPR variable component	0.07857	0.08274	0.08794	0.09288
	Capacity Factor	92%	92%	92%	92%
	GHG Adder	0.00561	0.00844	0.01096	0.01310
2010	MPR All-in	**0.10175**	**0.10748**	**0.11390**	**0.11761**
	MPR fixed component	0.02230	0.02310	0.02381	0.02239
	MPR variable component	0.07944	0.08438	0.09009	0.09522
	Capacity Factor	92%	92%	92%	92%
	GHG Adder	0.00715	0.01004	0.01264	0.01476
2011	MPR All-in	**0.10400**	**0.11046**	**0.11730**	**0.12110**
	MPR fixed component	0.02274	0.02356	0.02430	0.02284
	MPR variable component	0.08127	0.08690	0.09300	0.09825
	Capacity Factor	92%	92%	92%	92%
	GHG Adder	0.00894	0.01185	0.01452	0.01657
2012	MPR All-in	**0.10698**	**0.11405**	**0.12126**	**0.12509**
	MPR fixed component	0.02319	0.02403	0.02479	0.02331
	MPR variable component	0.08379	0.09002	0.09646	0.10178
	Capacity Factor	92%	92%	92%	92%
	GHG Adder	0.01100	0.01389	0.01657	0.01855
2013	MPR All-in	**0.10998**	**0.11776**	**0.12527**	**0.12915**
	MPR fixed component	0.02365	0.02452	0.02530	0.02378
	MPR variable component	0.08633	0.09324	0.09998	0.10536
	Capacity Factor	92%	92%	92%	92%
	GHG Adder	0.01271	0.01568	0.01838	0.02030
2014	MPR All-in	**0.11278**	**0.12122**	**0.12897**	**0.13290**
	MPR fixed component	0.02367	0.02455	0.02533	0.02382
	MPR variable component	0.08912	0.09667	0.10364	0.10908
	Capacity Factor	92%	92%	92%	92%
	GHG Adder	0.01425	0.01735	0.02005	0.02193
2015	MPR All-in	**0.11605**	**0.12503**	**0.13290**	**0.13690**
	MPR fixed component	0.02369	0.02458	0.02536	0.02385
	MPR variable component	0.09236	0.10045	0.10754	0.11305
	Capacity Factor	92%	92%	92%	92%
	GHG Adder	0.01585	0.01909	0.02174	0.02358
2016	MPR All-in	**0.11971**	**0.12915**	**0.13706**	**0.14111**
	MPR fixed component	0.02372	0.02461	0.02540	0.02389
	MPR variable component	0.09599	0.10454	0.11166	0.11723
	Capacity Factor	92%	92%	92%	92%
	GHG Adder	0.01753	0.02090	0.02346	0.02526
2017	MPR All-in	**0.12367**	**0.13352**	**0.14144**	**0.14549**
	MPR fixed component	0.02375	0.02465	0.02543	0.02392
	MPR variable component	0.09991	0.10888	0.11601	0.12157
	Capacity Factor	92%	92%	92%	92%
	GHG Adder	0.01928	0.02274	0.02520	0.02696
2018	MPR All-in	**0.12802**	**0.13814**	**0.14603**	**0.15001**
	MPR fixed component	0.02379	0.02468	0.02546	0.02395
	MPR variable component	0.10423	0.11346	0.12057	0.12606
	Capacity Factor	92%	92%	92%	92%
	GHG Adder	0.02111	0.02459	0.02696	0.02867
2019	MPR All-in	**0.13271**	**0.14298**	**0.15080**	**0.15464**
	MPR fixed component	0.02382	0.02472	0.02549	0.02398
	MPR variable component	0.10889	0.11826	0.12531	0.13066
	Capacity Factor	92%	92%	92%	92%
	GHG Adder	0.02301	0.02645	0.02873	0.03038
2020	MPR All-in	**0.13776**	**0.14797**	**0.15578**	**0.15937**
	MPR fixed component	0.02386	0.02476	0.02552	0.02401
	MPR variable component	0.11390	0.12321	0.13026	0.13537
	Capacity Factor	92%	92%	92%	92%
	GHG Adder	0.02500	0.02831	0.03050	0.03208

APPENDIX B
Utility's 2008 Time-of-Delivery (TOD) periods and factors

PG&E[55]

Month	Period	Definition	Factor
June - September	Super-Peak	Hours Ending (HE) 13-20 Monday-Friday (except NERC holidays)	**2.01**
	Shoulder	HE 7-12, 21 and 22 Monday-Friday (except NERC holidays); HE 7-22 Saturday, Sunday and all NERC holidays	**1.14**
	Night	HE 1-6, 23 and 24 all days (including NERC holidays)	**0.72**
October - February	Super-Peak	Defined above	**1.09**
	Shoulder	Defined above	**0.96**
	Night	Defined above	**0.78**
March - May	Super-Peak	Defined above	**1.13**
	Shoulder	Defined above	**0.86**
	Night	Defined above	**0.63**

[55] PG&E 2008 RPS Solicitation, pro forma contract, pp. 30-31. http://www.pge.com/includes/docs/word_xls/b2b/wholesaleelectricsuppliersolicitation/AttachmentGAsAvailableFormPPARev022908.DOC

SCE[56]

Season	Period	Definition	Factor
Summer June - September	On-Peak	WDxH[1], noon-6 pm	**3.13**
	Mid-Peak	WDxH, 8-noon, 6-11 pm	**1.35**
	Off-Peak	All other times	**0.75**
Winter October - May	Mid-Peak	WDxH, 8 am-9 pm	**1.00**
	Off-Peak	WDxH, 6-8 am, 9 pm-midnight; WE/H[2] 6 am-midnight	**0.83**
	Super-Off-Peak	Midnight-6 am	**0.61**

1/ WDxH is defined as weekdays except holidays
2/ WE/H is defined as weekends and holidays

SDG&E[57]

Season	Period	Definition[1]	Factor
Summer July - October	On-Peak	Weekdays 11am-7pm	**1.6411**
	Semi-Peak	Weekdays 6am-11am; Weekdays 7pm-10pm	**1.0400**
	Off-Peak	All other hours	**0.8833**
Winter November - June	On -Peak	Weekdays 1pm-9pm	**1.1916**
	Semi -Peak	Weekdays 6am-1pm; Weekdays 9pm-10pm	**1.0790**
	Off-Peak	All other hours	**0.7928**

1/ All hours during National Electric Reliability Council (NERC) holidays are Off-Peak.

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[56] SCE 2008 RPS Solicitation, pro forma contract, Exhibit K, p. 2.
http://www.sce.com/nrc/rfp/2008_RPS_Appendix_B_ProForma_Agreement.doc

[57] SDG&E 2008 RPS Solicitation, pro forma contract, p. 39.
http://www.sdge.com/documents/rfo/renewablerfo2008/ModelPPA.doc

APPENDIX C

2008 MPR California and Henry Hub Gas Forecast (2009 – 2045)

Year	2008 MPR Henry Hub Forecast (nominal$)	2008 MPR CA Gas Forecast (nominal$)
2009	$10.47	$10.60
2010	$9.69	$9.97
2011	$9.40	$9.68
2012	$9.25	$9.54
2013	$9.14	$9.44
2014	$9.12	$9.43
2015	$9.19	$9.50
2016	$9.27	$9.60
2017	$9.39	$9.73
2018	$9.55	$9.90
2019	$9.72	$10.08
2020	$9.89	$10.27
2021	$10.04	$10.56
2022	$10.39	$10.90
2023	$10.91	$11.41
2024	$11.52	$12.02
2025	$12.05	$12.56
2026	$12.40	$12.91
2027	$12.96	$13.48
2028	$13.48	$14.00
2029	$13.95	$14.48
2030	$14.46	$14.99
2031	$14.95	$15.49
2032	$15.44	$16.01
2033	$15.94	$16.52
2034	$16.17	$16.77
2035	$16.67	$17.28
2036	$17.16	$17.80
2037	$17.65	$18.31
2038	$18.15	$18.82
2039	$18.64	$19.34
2040	$19.13	$19.85
2041	$19.63	$20.37
2042	$20.12	$20.88
2043	$20.61	$21.39
2044	$21.11	$21.91
2045	$21.60	$22.43

APPENDIX D
2008 MPR Gas Forecast Inputs

Row No.	Input Category	Input	Units	Baseload Inputs	Notes
1	Henry Hub Forecasts /1	CERA, PIRA, or Global Insight /2	$/MMBtu	N/A	20 yr. Henry Hub forecast (private - purchased)
2	General Inputs	Transaction Cost	$/MMBtu	$0.082	D.04-06-015, pg. 26, reafirmed in D.05-12-042 (pg. A-7)
3		Transportation Escalation Rate	Percent-%	1.99%	Average of EIA 2008 GDP Chain-Type Price Index. See 2008 MPR model - Delivery_Tar Tab (Cell E9)
4		20-year WACC	Percent-%	8.51%	2008 MPR model - Cost Cap Tab (Cell D9)
5	Municipal Surcharge	SoCal Muni Surcharge	Percent-%	1.462%	Schedule G-MSUR - http://www.socalgas.com/regulatory/tariffs/tm2/pdf/G-MSUR.pdf
6		PG&E Muni Surcharge	Percent-%	0.950%	PG&E Rate Schedule GC-P: (1) http://www.pge.com/rates/tariffs/GCP_Current.xls and (2) http://www.pge.com/rates/tariffs/GSUR_Current.xls
7	PG&E Gas Distrib. Rate	Customer Access Charge	$/day	$182	http://www.pge.com/tariffs/pdf/G-EG.pdf
8		Proxy Plant Capacity	MW	500	2008 MPR model - Delivery_Tar Tab (Cell E15)
9		Heat Rate	MMBtu/MWh	6.88	2008 MPR model - Delivery_Tar Tab (Cell E16)
10		Capacity Factor	percent-%	92%	2008 MPR model - Delivery_Tar Tab (Cell E17)
11		Monthly Gas Consumption	MMBtu	75,750	(Row 8 * Row 9* Row 10) * 24 hours
12		Unit Cost of Customer Access Charge	$/MMBtu	$0.0024	Row 7 / Row 11
13		Transportation Charge	$/MMBtu	$0.1827	http://www.pge.com/tariffs/pdf/G-EG.pdf
14	SoCal Gas Distrib. Rate	Customer Charge	$/month	$0.00000	http://www.socalgas.com/regulatory/tariffs/tm2/pdf/GT-F.pdf
15		Transmission Charge	$/MMBtu	$0.2936	http://www.socalgas.com/regulatory/tariffs/tm2/pdf/GT-F.pdf
16		Interstate Transportation Cost Surcharge	$/MMBtu	$0.0005	http://www.socalgas.com/regulatory/tariffs/tm2/pdf/GT-F.pdf

1/ The Henry Hub forecasts are inputs for the MPR - Henry Hub forecast - there are no specific baseload values.
2/ Due to contractual obligations requiring the Commission to keep the forecast confidential, staff can not reveal which of the three firms the forecast was purchased from.

APPENDIX E
2007 MPR Non-Gas Inputs

Row No.	Input Category	Input	Units	Baseload Inputs	Escal. Rates/yr.	Notes
1	Capital Inputs	Total capital cost January 1 - 1st operational yr.	$/kw	$1,182	2.15%	Per D.05-12-042, Staff conducted a survey of actual plant costs in CA. Four plants were selected and an average was calculated
2		Fixed O&M	($/kW-yr) 1st operational yr.	$9.70	1.99%	CEC Cost of Generation Report CEC-200-2007-001-SF Table 6, p. 18. Escalated from $2007 to $2009 using EIA GDP Chain-type Price Index.
3		Variable O&M	(mills/kWh) 1st operational yr.	$4.35	1.99%	CEC Cost of Generation Report CEC-200-2007-001-SF Table 6, p. 18. Escalated from $2007 to $2009 using EIA GDP Chain-type Price Index.
4		New & Clean heat rate	Btu/kWh HHV	6704	n.a.	Per D.05-12-042, Staff used the the "new & clean" heat rate for an F-Series (GE S207FA) CC Turbine, adjusted for Higher Heating Value
5		Heat rate degradation factor	Percent-%	1.74%	n.a.	Per D.05-12-042, Staff contacted GE for an appropriate heat rate degradation factor for an F-series CC turbine. GE provide a degradtion curve that calculated the average degradation over the life of the project.
6		Average heat rate	Btu/kWh HHV	6924	n.a.	Average heat rate over life of plant, taking into account the impact of Higher Heating Value, degradation, dry cooling, and starts/stops
7	Finance Inputs	20-year WACC	Percent-%	8.51%	n.a.	Weight-Average Cost of Capital = (Cost of Equity x Equity %) + (Cost of Debt x (1-tax rate) x Debt %)
8		Cost of LT Debt	Percent-%	7.84%	n.a.	Per D.05-12-042, Cost of Debt (industrial firms) = risk free rate (20 year T-Bill) + risk premium (mid point between BBB & B+). http://www.bondsonline.com, May 13, 2008
9		Cost of Equity	Percent-%	12.38%	2.00%	Per D.05-12-042, Cost of Equity = risk free rate (20-yr Tbill) + risk premium (equity) + mid-cap risk premium (equity). http://www.bondsonline.com, May 13, 2008
10		Debt as % of total cost	Percent-%	50%	n.a.	Per D.05-12-042, LT debt ratio for BBB rated company
11		Debt Term	Years	20	n.a.	Adopted in D.04-06-015 and reaffirmed in D.05-12-042
12		Insurance as % of plant cost	Percent-%	0.60%	1.99%	Same value used for 2004 MPR. Energy Division contacted insurance brokers for quotes and calculated an average value.
13	Power Delivery Inputs	Transformer Loss Factor	Percent-%	0.50%	n.a.	Loss factor recommended by parties and used in 2004 MPR calculation
14		Generation Meter Multiplier (GMM) to load center	Percent-%	98.5%	n.a.	Not Used. Pursuant to D. 08-10-026, the MPR Model assumes delivery at the busbar
15		Capacity Factor	Percent-%	92%	n.a.	Per D.08-10-026
16	Tax Rate Inputs	Federal Tax Rate	Percent-%	35%	n.a.	Tax rate proposed by the parties and used in the 2004 MPR calculation
17		State Tax Rate	Percent-%	8.84%	n.a.	Tax rate proposed by the parties and used in the 2004 MPR calculation
18		Total Effective Tax Rate	Percent-%	40.75%	n.a.	Effective Tax = Federal Tax * (1 - State Tax) + State Tax
19		Property taxes as % of plant cost	Percent-%	1.20%	n.a.	Same value used for 2004 MPR. Energy Division averaged the property tax rates for 14 counties in which power plants were constructed (or under construction) in the last 5 years.
20	Gas Forecast	20yr gas forecast - 2009 levelized	$/MMBtu	$10.42	n.a.	Output from CA_Gas_Forecast Tab (Cell N42) in 2008 MPR model
21	GHG	GHG Compliance Cost	$/Ton	$15.00	n.a.	($15 in 2013). Climate Change and Power: Carbon Dioxide Emissions Costs and Electricity Resource Planning. Synapse Energy Economics. March 2, 2007. Updated July 2008, Synapse 2008 CO2 Price Forecast (in $2007). (Table 2, p. 16) http://www.synapse-energy.com/Downloads/SynapsePaper.2008-07.0.2008-Carbon-Paper.A0020.pdf

Application No:	A.
Exhibit No.	SCE-1
Witnesses:	R. Fisher D. Klun M. Nelson R. Perez G. Rodrigues D. Snow

SOUTHERN CALIFORNIA
EDISON

An *EDISON INTERNATIONAL* Company

(U 338-E)

Solar Photovoltaic (PV) Program Testimony

Before the

Public Utilities Commission of the State of California

March 27, 2008
Rosemead, California

1469812

Solar Photovoltaic (PV) Program

Table Of Contents

Section	Page	Witness
I. INTRODUCTION AND OVERVIEW	1	M. Nelson
II. NEED FOR PROGRAM	3	
A. Implementation Of SCE's Proposed Large Solar PV Program Will Contribute To State Goals To Promote Both Solar PV and Renewable Power	3	
B. SCE Can Best Develop Solar PV Program	7	
1. System Operation And Integration Into The CAISO System	7	
2. Customers Receive Credit For Solar PV Output	7	
3. Existing Business Relationships And Resources Can Be Leveraged	8	
4. SCE's Extensive History And Experience With Solar Generation	9	
C. SCE's Solar PV Program Will Increase The Probability That The Million Solar Roofs Goal Will Be Met	11	
D. Solar PV Program Can Improve Efficiencies of Elements Of The California Solar PV Market To Reduce Costs	12	
E. The Solar PV Program Will Provide Unique Benefits And Challenges From the Addition Of Large Amounts of Solar PV To SCE's System	15	
F. The Solar PV Program Will Provide Valuable Information To The State	17	
1. Information On Interaction Of Solar PV With The Distribution System	18	
2. Information And Experience Forecasting Solar PV Output	19	
3. Information On Workforce Training	19	
4. Information On Streamlining Of Tariff Applications For Solar PV	19	

Solar Photovoltaic *(PV) Program*

Table Of Contents (Continued)

Section	Page	Witness
III. PROGRAM DESCRIPTION	20	R. Perez
A. Size of Program	20	
B. Length of Program	20	
C. Description of Facilities	22	
1. Type of Facilities	22	
a) Crystalline Technology	22	
b) Thin Film Technology	24	
c) Technology Comparison	26	
d) Inverters and Balance of System	27	
e) PV Module Mounting Systems	28	
f) Building Integrated PV	30	G. Rodrigues
2. Size of Facilities	32	R. Perez
3. Location and Configuration of Facilities	33	
4. Interconnection Facilities	35	
5. Data Acquisition System (DAS)	37	
6. Leasing Rooftop Space For Facilities	38	
IV. PROGRAM COST ESTIMATE	40	
A. Capital	40	
1. Generating Facilities Cost	40	
2. Installation Cost	40	
3. Interconnection Costs	42	
4. Total Program Capital Costs	42	
B. Operation & Maintenance Cost	44	
1. Roof Lease Payments	44	

Table Of Contents (Continued)

Section	Page	Witness
2. Maintenance Cost	45	
3. Staffing	45	
V. RATEMAKING	48	D. Snow
A. Introduction	48	
B. Forecast of SCE's Solar PV Program Revenue Requirements	48	
1. Capital Expenditures/Additions	50	
2. Depreciation Expense	51	R. Fisher
a) Generating Facilities Plant	51	
(i) PV Modules and Balance of System Components	51	
(ii) PV Rack	53	
b) General Plant	53	
c) Distribution Plant	53	
3. Rate of Return	54	D. Snow
4. O&M Expense	54	
5. Income Taxes	55	D. Klun
C. Description of Solar PV Program Balancing Account (SPVPBA)	56	D. Snow
D. Proposed Reasonableness Review and Standard for Reasonableness Review	57	
1. Inflation Adjustment	58	P. Hunt
2. Reasonableness Review Procedure	58	D. Snow
Appendix A Witness Qualifications	60	

Solar Photovoltaic (PV) Program

List of Tables

Section		Page

Table II-1 Typical Residential Solar PV Installation (3 kW +/- 0.05).....9

Table II-2 Typical Large Residential Solar PV Installations (900 kW – 1MW).....9

Table III-3 Estimated Solar PV Program Schedule.....22

Table IV-4 Estimated Hardware Cost for 1 MW Solar PV Project (2008$).....40

Table IV-5 Estimated Installation Cost for 1 MW Solar PV Project (2008$).....41

Table IV-6 Summary of Capital Costs of Solar PV Program (2008$).....43

Table IV-7 Estimated Yearly O&M Costs for a 1 MW Solar PV Project (2008$).....45

Table IV-8 Solar PV Program Management Labor Forecast Increase For New Employees (2008$).....46

Table IV-9 Forecast Summary of Staffing Costs of Solar PV Program.....47

Table V-10 Summary of Solar PV Program Estimated Revenue Requirements (O&M and Capital Costs) Thousands of Dollars.....49

Table V-11 Summary of Solar PV Program Calendar Year Capital Expenditures $millions.....51

Table V-12 Summary of Future Decommissioning Expenses (included in Depr. Expense) thousands of dollars.....52

Table V-13 Summary of Solar PV Program Calendar Year Estimated O&M Expenditures $millions.....55

Table V-14 Reasonableness Review Threshold For Direct Solar PV Program Capital Costs (2008$).....58

List of Figures

Section		Page

Figure II-1 Chart of Solar PV Output vs. Time of Day Center for the Study of Energy Markets, 2005 16

Figure III-2 Typical Crystalline Solar PV Module 175 watts measuring approximately 64”x 32” x 1.75” and weighing 33 pounds 23

Figure III-3 Typical Amorphous Thin Film Module Measuring 18 feet long by 15.5” wide and Weighing_17 lbs. 25

Figure III-4 Typical Rigid Thin Film PV Module Measuring 4 feet long by 2 feet wide and Weighing 26.5 lbs. 26

Figure III-5 500kW ac Inverter and Transformer Inverter measuring 7.6”x9.6’x3’6” (HxWxD) transform measuring 5’x4’x4’ (HxWxD) and weighing combined approximately 9,800 pounds. 28

Figure III-6 1.2 MW Non-Penetrating Solar PV System on Commercial Rooftop in Sacramento, CA 30

Figure III-7 Photograph of the Long Beach Convention and Entertainment Center illustrating the solar PV array is not visible from street level 33

Figure III-8 Proposed System Single Line Simplified Interconnection 37

Figure III-9 Proposed System Single Line Complex Interconnection 37

I.

INTRODUCTION AND OVERVIEW

California is endowed with abundant solar resources. In recent years, the State has taken bold steps to develop this resource, but more can be done. In this application, Southern California Edison Company (SCE) proposes the Solar Photovoltaic (PV) Program, an aggressive program to develop up to 250 megawatts (MW)[1] of utility-owned Solar PV generating facilities ranging in size from 1 to 2 MW[2] each. This program is targeted at the vast untapped resource of commercial and industrial rooftop space in SCE's service territory.[3] It will aggressively bridge the gap between small and large scale solar installations. It will also use rooftop space from entities that would not otherwise be typical candidates for the net energy metering tariff.[4] SCE proposes to develop these projects at a rate of approximately 50 MW per year at an average cost of $3.50/Watt (W). If the program is successful, SCE may seek additional authority to expand the program to 500 MW. An expansion to 500 MW would seek to maintain the momentum of that success. So, there is no hiatus in installing new systems. SCE's proposed Solar PV Program is a near-term bold step to further develop California's solar resources independent of the need for major new transmission facilities.

California has implemented an aggressive program, the California Solar Initiative (CSI), to facilitate the development of solar projects. The Renewable Portfolio Standard (RPS) also facilitates development of solar projects, along with other renewable resources. But these programs have left a large solar gap. As described in detail below, SCE's Solar PV Program is uniquely qualified to fill this

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[1] Unless otherwise specified, any reference to energy output in this filing follows the common convention within the PV industry, which is to refer to output as PV panel direct current (dc) output. Additionally, SCE proposes using installed dc output in reasonableness reviews because installation occurs in dc panels. Based on sample calculations, the conversion factor of 0.90 will convert from MW dc to MW alternating current (ac) using the California Energy Commission's ac MW conversion (i.e., multiply MW dc by 0.90 to obtain MW CEC-ac Rating).

[2] SCE envisioned the individual Solar PV Program installations to range from 1 to 2 MW. As the program proceeds, however, some installations may be larger or smaller than this range due to roof size, circuit loading, optimal use of inverters or other considerations.

[3] While SCE presently intends the program for rooftops, SCE may pursue other locations and opportunities for placement of Solar PV facilities.

[4] Net energy metering installations, which are limited to 1 MW, allow utility customers to receive California Solar Initiative (CSI) incentives and off-set their energy usage by their solar PV system output over a 12-month period.

gap, because this bandwidth (1 to 2 MW facilities) of the solar resource is going untapped. There is currently no program in place to develop this market segment. By further developing this aspect of the solar market, the Solar PV Program will contribute in the near term to achieving the State's CSI million solar rooftop goals. It will also contribute to meet renewable goals.

Furthermore, SCE anticipates that the aggressive development of this "middle market" for solar PV in southern California will attract investment, manufacturing, and expertise to California's solar industry. This will increase supply options and should reduce the cost for all solar PV products and services. In turn, broadening and deepening the local solar PV market will produce savings in the State's CSI program. Simply stated, reducing the installed cost of solar PV will leverage the subsidy dollars already allocated to the CSI program and produce more capacity and energy deliveries for California's investment in solar PV.

Finally, SCE is uniquely qualified to develop this market sector. These facilities will interconnect at the utility distribution level and will be sited at SCE retail customer locations. SCE's strong balance sheet, institutional expertise, and SCE's long history of solar "firsts" makes it a logical candidate to pioneer innovations in the untapped industrial and commercial rooftop market through this program.

II.

NEED FOR PROGRAM

A. Implementation Of SCE's Proposed Large Solar PV Program Will Contribute To State Goals To Promote Both Solar PV and Renewable Power

In 2006, Governor Schwarzenegger, working with the Commission and the California Legislature, established a CSI designed to develop 3,000 MW of rooftop solar PV installations by 2016. The State has authorized substantial incentives to achieve this aggressive target of 1 million rooftop solar installations.

Solar is a renewable resource. The State has adopted one of the most aggressive RPS programs in the country. The goal is to have 20% of SCE's customers' energy needs met with renewable resources.[5] Although not specifically targeted at solar resources, the RPS program has the potential to yield substantial development of large central-station solar resources over the next decade. Several large-scale, central station solar installations are under contract or in development as a result of SCE's RPS program solicitations.

But these programs have left a large solar gap. California's CSI is geared to develop very small solar PV installations. California's RPS program is geared to develop very large solar (not necessarily PV) installations. Neither program, however, is well suited to develop medium-scale PV solar installations in the 1 to 2 MW range in the near-term due to size and transmission limitations. And although the economics of 1 to 2 MW PV facilities are far superior to typical rooftop facilities, they are too large to take full advantage of the State's CSI and net energy metering[6] programs. Many large commercial rooftops have site electrical loads that do not match the energy production of a 1 to 2 MW

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[5] Public Utilities Code Section 399.15(b)(1) sets forth a goal that 20% of retail electric sales be served by renewable resources by 2010:

> Each retail seller shall, pursuant to subdivision (a), increase its total procurement of eligible renewable resources by at least an additional 1% of retail sales per year so that 20% of its retail sales are procured from eligible renewable energy resources no later than December 31, 2010…

[6] Net energy metering installations are limited to 1 MW. Distributed Generation installations that receive CSI or Self Generation Interconnection Program (SGIP) funds are limited to 5 MW in size, but may receive incentives for up to 1 MW under CSI even if they received 1 MW under SGIP for a potential total incentives of 2 MW per site.

solar PV facility. Conversely, other utility-scale solar technologies, such as parabolic trough, Stirling dish and "power tower" installations are not commercially practicable in distributed configurations, urban and semi-urban locations, or at the 1 to 2 MW scale. SCE's Solar PV Program fills this solar gap. There is currently no other program in place to develop this important market sector. SCE proposes immediate start-up of the Solar PV Program to bridge the solar gap and to assist in meeting the State's renewable goals.

SCE's Solar PV Program is targeted at the vast untapped resource of commercial and industrial rooftop space in SCE's service territory. This program will aggressively bridge the gap between small and large scale solar installations. Although this program will focus on a fertile market sector undeveloped by either the CSI or RPS programs, the program will contribute to both goals. In CSI terms, this program has the potential to add over 80,000 "rooftop equivalents"[7] in five years or about 10% of the overall CSI goal of 1 million rooftops. SCE's program will also contribute in the near term to achieving the State's renewable energy goals. Because these installations will interconnect at the distribution level, they can be brought on line relatively quickly without the need to plan, permit, and construct the transmission lines. Larger scale renewable resources generally require transmission line construction to deliver their output to load centers.

SCE is currently pursuing transmission line permitting and construction as one way to help the State meet its renewable energy goals. In addition, SCE's actions to implement its Long Term Procurement Plan (LTPP) and RPS procurement activity are consistent with meeting the renewable goals. Decision No. (D.)06-05-039 states that "…, we will take into account whether or not each electrical corporation undertook all reasonable actions to comply [in meeting the State's renewable energy goals]. One of those actions is building, then owning and operating the [renewable] resource itself."[8] In addition, D.07-02-011 and D.08-02-008[9] stated that, "…we encourage IOUs to actively

[7] The State's CSI goal of 3,000 MW by 2016 is based on an average PV installation size of 3 kW, yielding 1 million rooftops. A "rooftop equivalent" is 3 kW. SCE's program goal of 250 MW installed by 2013 yields 83,333 rooftop equivalents.

[8] D.06-05-039, *mimeo*, p. 34.

[9] D.07-02-011 dated February 15, 2007, *mimeo*, p. 25 and D.08-02-008, *mimeo,* p. 33.

assess the feasibility of utility ownership, and pursue such ownership when and where it makes sense." While the primary purpose of the program is to help meet the State's ambitious solar roof goals, the Solar PV Program will also add to SCE's renewable portfolio in response to these challenges. Specifically, in 2009, the Solar PV Program installations will produce 0.1% of SCE's customer energy needs; by 2014, Solar PV Program installations will produce approximately 0.4% of SCE's customer energy needs. To assure the availability of this generation as soon as possible after approval of this application, SCE may begin implementation of the Solar PV Program in 2008, while awaiting a final Commission decision on this application.

The CPUC has articulated various policies that solar PV supports and advances. SCE's proposed Solar PV Program would advance the following policies adopted in D.06-01-024, implementing the CSI Program:[10]

- Development of solar technologies is consistent with state policy and provides California with a clean and reliable source of distributed energy.[11] SCE's proposed Solar PV Program will provide California with a clean and reliable source of distributed energy.
- The legacy California Energy Commission (CEC) and CPUC solar incentive programs, the Emerging Renewable Program, and the Self Generation Interconnection Program (SGIP), and the new CSI Program, although similar, provide incentives to different-sized projects and are funded by different utility rate components.[12] SCE's proposed Solar PV Program will be utility-owned. The Solar PV Program will produce energy from eligible renewable resources[13] for

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[10] The CSI Program provides detailed requirements for receiving funding for the installation and operation of solar PV projects under the Commission's incentive program. As authorized by the Commission and SB 1, Chapter 132, Statutes of 2006 (SB1, Murray), the CSI Program has a total budget of $2.1672, D. 06-12-033, December 14, 2006, *mimeo*, p. 27, billion to be used over 10 years, D. 06-08-028, August 24, 2006, *mimeo*, pp. 83, 88.

[11] D.06-01-024, dated January 12, 2006, Finding of Fact No. 1, *mimeo,* p. 39.

[12] Id. at Finding of Fact No. 2, *mimeo*, p. 39.

[13] An eligible renewable energy resources uses biomass, solar thermal, photovoltaic, wind, geothermal, fuel cells using renewable fuels, small hydroelectric generation of 30 megawatts or less, digester gas, municipal solid waste conversion, landfill gas, ocean wave, ocean thermal, or tidal current. The term "eligible renewable energy resource" is further defined in California Public Utilities Code Section 399.12(c) and California Public Resources Code 25741(b).

SCE's customers. To the contrary, incentive programs give the customer generator the renewable energy credit which is not currently eligible for use in California.

- A 10-year commitment by the state to provide incentives for solar installations provides a signal to manufacturers and other industry participants that encourages innovation and development.[14] SCE's proposed Solar PV Program will provide a signal to industry participants that large-scale solar PV projects on commercial-size roofs are a viable power source. This will transform the market for installation of such projects without depending on incentives.
- All solar energy technologies have the potential to reduce demand for fossil fuels and investments in more traditional energy resources and provide environmental benefits.[15] SCE's proposed Solar PV Program also has the potential to reduce demand for fossil fuels.

SCE proposes this program in furtherance of the State's goal to increase the installation of solar PV technology. Our proposed program will achieve this goal at lower cost and will further help jump-start the solar industry. The cost to our customers of the Solar PV Program will be significant, but far less than the cost of CSI implementation.[16] For these reasons, if the CSI goals become mandatory for SCE's customers, SCE requests that the MWs installed under its program be "credited" towards its customers' targets. In addition, the cost impact on our customers is not insubstantial. They already bear the annual cost of the CSI program and the carrying costs of the Solar PV program if SCE's application is granted. This may justify reducing their share of the State's CSI goals and potentially some portion of the CSI program costs our customers contribute.

SCE proposes a base case budget of about $875 million and a reasonableness threshold of $962.5 million to be used over 5-years to produce 250 MW of solar PV power. SCE's program will improve the efficiency and increase use of solar PV consistent with State goals and policies.

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[14] Id. at Finding of Fact No. 4, *mimeo,* p. 39.

[15] Id. at Finding of Fact No. 5, *mimeo,* p. 39.

[16] See Section II.B.3, infra.

B. SCE Can Best Develop Solar PV Program

1. System Operation And Integration Into The CAISO System

SCE, as operator of its distribution system, has the technical expertise to evaluate the various solar PV technologies and their impacts on its distribution system. SCE will study solar PV panel and inverter efficiency. SCE can monitor system status and cost-effectively facilitate repair of these systems through its field personnel. SCE is the only California Independent System Operator (CAISO) participant scheduling solar resources into the CAISO electric grid. SCE is very aware of the challenge solar generated electricity creates. Solar PV resources over 1 MW must schedule power with the CAISO and will likely participate in the CAISO's Participating Intermittent Resource Program (PIRP).

The current PIRP does not include solar resources. SCE will work with the CAISO to formulate protocols, data acquisition system requirements and forecast methods for solar PV resources just as SCE has done with the wind PIRP. The Solar PV Program will provide SCE with operational control of a utility-owned solar generating resource. This will greatly facilitate development of a solar PIRP.

2. Customers Receive Credit For Solar PV Output

Solar PV output is eligible to be counted towards the State's renewable goal of meeting 20% of customers energy needs with renewable resources. However, utilities and their customers do not receive credit for the output associated with Solar PV projects installed pursuant to the State's CSI program, as the customer/owner of the PV facility retains the renewable energy credit.[17] Solar PV installed by SCE under the Solar PV Program will count towards SCE's RPS goals. The Solar PV Program would provide 50 MW each year for 5 years. A generating facility with a 45 MW capacity and an 18% capacity factor is expected to generate 70,956 MW[18] per year. In 2009, this would equate to approximately 0.1% of SCE's customer energy needs. A generating facility with a 225 MW capacity

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[17] See, D.07-01-018, *mimeo*, p. 20 and Ordering Paragraph 1, *mimeo*, p. 31..

[18] Expected generation shown is assumed to be ac MWh like any other generation SCE procures under the RPS program.

and an 18% capacity factor is expected to generate 354,780 MWh[19] per year. In 2014, this would equate to approximately 0.4% of SCE's customer energy needs. This supports the State's overall goals.

3. Existing Business Relationships And Resources Can Be Leveraged

SCE has established electricity supply relationships with potential vendors and commercial building lessors who are also its customers. These entities see SCE as a reliable business partner, in part because SCE has been in business for over 100 years. SCE's utility operations are viewed as a stable, competent, and reliable. SCE's strong balance sheet and procurement expertise allow the utility to readily negotiate contracts with rooftop owners and vendors. SCE expects to receive volume discounts for its proposed investment. Multiple developers are unlikely to achieve the same efficiencies and favorable pricing levels. Because of these established relationships and volume discounts, SCE can move quickly and efficiently to develop the Solar PV Program.

SCE can expand solar PV implementation at a lower cost than is currently in effect for CSI customers. Tables II-1 and II-2 below compile CEC data from CSI Photovoltaic Installation Applications from January 1, 2007 to March 1, 2008. The chart compares total installed costs for residential (3 kW nominal size) and large commercial (900kw to 1 MW size) solar PV projects. On average, residential solar PV installations cost $8.25/W, while large commercial installations cost $6.78/W. SCE's Solar PV Program budgeted cost is $3.50/W on average and proposed reasonableness threshold is $3.85/W on average. SCE expects to achieve these substantially lower installed costs through the volume of the proposed projects creating economies of scale and by partnering with PV suppliers providing newer technologies at considerable cost savings.

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[19] Id.

Table II-1
Typical Residential Solar PV Installation (3 kW +/- 0.05)

Utility	#	Average Total Cost	Average Nameplate Rating (kW)	Average Cost per Watt ($/W)
SCE	42	$24,206	3	$8.07
PG&E	103	$25,625	3	$8.54
CCSE	11	$24,591	3	$8.22

Table II-2
Typical Large Residential Solar PV Installations (900 kW – 1MW)

Utility	#	Average Total Cost	Average Nameplate Rating (kW)	Average Cost per Watt ($/W)
SCE	29	$7,617,496	1,165	$6.56
PG&E	28	$8,191,391	1,160	$7.08
CCSE	5	$7,698,611	1,190	$6.47

4. SCE's Extensive History And Experience With Solar Generation

In addition to its location, strong balance sheet and institutional expertise, SCE's long history of solar "firsts" makes it a logical candidate to pioneer innovations in the untapped industrial and commercial rooftop market. Among other things, SCE developed and operated the groundbreaking 10 MW Solar One project as the first utility solar "power tower" in the 1980s. SCE followed up with the

Solar Two project in the 1990s that demonstrated 28 hours of continuous grid connected generation from solar power tower technology using molten salt energy storage technology. This is a world record that still stands today. This storage technology is now being deployed as an important component of today's larger solar generating stations being built in Spain and of those proposed for California and Arizona.

In partnership with McDonnell Douglas, SCE also developed the 25 kW Stirling dish technology. This project set a world record for efficiency, converting solar energy into electricity at a rate of 29.4% in 1984. SCE sold this technology to Stirling Energy System (SES) in 1996 and just this year SES and Sandia National Laboratory announced a new world record for efficiency, converting the sun's energy into useable electricity at 31% efficiency. This would not have been possible without the years of SCE's pioneering effort in the 1980s.

SCE also partnered with ARCO Solar to build and operate the first large, 1 MW, solar PV array that used concentrating lens technology. SCE was lead contractor for the CEC PIER program that installed and monitored more than a dozen rooftop solar PV systems in the early to mid-1990s. This proved that grid-connected solar PV was feasible. In addition, SCE installed highly visible demonstration solar PV projects located at the Santa Monica pier and the South Coast Air Quality Management District's (SCAQMD) "solar carport." The distribution circuit unloading project installed at the Huntington Library using solar PV to defer an underground cable replacement was also a first.

SCE also has Power Purchase Agreements (PPAs) for 359 MW ac nameplate capacity with the nine Solar Energy Generating Station (SEGS) facilities that have been operating for over 20 years in the Mojave Desert. Presently, these are the only PPAs producing thermal solar generated electricity in California and represent the vast majority of the solar production in the nation today.[20]

Finally, in the 1990s, SCE pioneered flexible PV with Texas Instruments and also provided two solar PV retail tariffs to support the Solar Neighborhoods program.

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[20] Nevada Solar One, a 64 MW SEGS technology solar facility, commenced operation in June, 2007. APS also operates a 1 MW test facility which went into service in 2007. This makes total installed and operating concentrating solar power technology nameplate capacity 424 MW.

Over the course of nearly 30 years, SCE has developed a broad institutional knowledge from its relationship with sellers as well as from operating just about every solar generating technology. This knowledge and experience will form a strong foundation for the Solar PV Program. As indicated above, the Solar PV Program will provide about 0.4% of SCE's estimated customer energy needs in 2014.

C. SCE's Solar PV Program Will Increase The Probability That The Million Solar Roofs Goal Will Be Met

In the LTPP proceeding, the Commission found that:

> "If an [Investor-Owned Utility (IOU)] proposes a [Utility-owned Generation] project outside of a competitive [Request for Offers (RFO)], it is reasonable to require the IOU to make a showing that holding a competitive RFO is infeasible."[21]

According to California Solar Initiative (CSI) data, more than 40% of the applications for projects over 900 kW in SCE's service territory have been cancelled or suspended since CSI was implemented in January 2007.[22] SCE has the financial stability and business reputation that will enhance the development opportunities for solar installations generally. The Solar PV Program provides utility customers and the State a substantial increase in the probability that 250 MW of solar PV systems will be available to meet the State's goals over the next five years.

Large PV Projects installed by independent power producers provide valuable information for those firms involved in the project, but less value to the State or the PV industry as a whole. SCE plans to share the information it gains through the installation and operation of Solar PV Program. This type of information gathering and technology assessment associated with the solar PV technology is inconsistent with the concept of private-party completion and low bidders. If the Commission wishes to jump start the competitiveness of roof top solar PV as a renewable resource, SCE's Solar PV Program will further that goal. It will thoroughly evaluate solar PV technology and will support greater efficiency in the California solar PV market.

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[21] D.07-12-052, Finding of Fact No. 100, *mimeo,* at p. 286, p. 2, and fn. 240, p. 210.

[22] These are mostly legacy SGIP solar PV installations. The SGIP for solar PV was rolled into the CSI in January 2006.

SCE is currently developing the procurement process for the PV Systems (i.e., PV panels, inverters, balance of plant), installation, and leasing of the roofs. SCE will rely heavily on competitive solicitations for most procurement activities. This will provide the most cost-effective solution for our customers. Because the Request for Proposals (RFP) process is lengthy, SCE may issue directed purchase orders to selected vendors to expedite the initial installations in parallel with the overall program competitive solicitations.

D. Solar PV Program Can Improve Efficiencies of Elements Of The California Solar PV Market To Reduce Costs

SCE proposes to pursue large-scale implementation of 50 MW of solar PV projects of 1 to 2 MW on commercial rooftops each year for five years. SCE seeks to create efficiencies in the California market for solar PV equipment and installation resources, but not to overheat the market for solar PV panels, equipment, and installation resources. In SCE's judgment, 50 MW per year will trigger new efficiencies, but not drive prices up due to materials shortages or lack of manufacturing capacity.[23] The solar PV modules required for the Solar PV Program will not impact product availability for other solar PV facilities in California. During the last several months, the solar PV module manufacturers have made significant progress towards securing critical materials, such as silicon, needed to meet product demand. The largest solar PV module manufacturers are adding production lines to meet demand. New solar PV module manufacturers located overseas continue to enter the U.S. market. Additionally, emerging technologies using new materials are on the verge of commercial viability.

The Solar PV Program system installations can begin a few months after regulatory approval or even earlier with implementation of a memorandum account prior to final Commission approval. The Solar PV Program will aid the market for rooftop solar PV generation. The goals are to drive installation costs down, improve technology and pricing of certain component parts, increase installation

[23] If the program is successful, SCE may seek Commission authority to increase the overall size of the Solar PV Program to 500 MW. The additional 250 MW would likely be realized through the combination of installing more MW per year and lengthening the program term itself.

efficiency, and improve installation methods. Another related goal is to develop a trained in-state installation work force.

SCE's installations of 1 to 2 MW projects totaling up to 50 MW each year should help to (1) refine production of solar PV system parts, (2) improve the capabilities of ancillary equipment, such as inverters, (3) increase the use of otherwise vacant large commercial rooftops in California, and (4) increase the efficiency of installation. To meet Solar PV Program goals, SCE will order large volumes of solar PV panels, mounting, and electrical hardware each year. The increased scale of manufacturing required by such orders should lead manufacturers to improve designs and to increase their capability to produce such parts. Manufacturers will likely also have the incentive to improve manufacturing processes to incorporate economies of scale that drive prices down.

SCE expects to order, on average, 50 MW in nameplate rating of large-scale inverters each year. This will provide incentives to improve inverter technology. Improvements in technology are possible through SCE coordination with inverter manufacturers. Solar data that SCE collects may suggest design changes to inverters that could enhance PV performance. SCE could then coordinate with inverter manufactures to implement these design changes. For example, if data collection and subsequent analysis suggest solar inverters could cost-effectively add voltage support, manufacturers could design future inverters to do so. Improvements in technology are always possible. But through SCE participation in code committees and interconnection tariff rules establishing the standards for inverters designed and certification, SCE can help facilitate more ready acceptance of changes.

SCE plans to interconnect 50 MW of these projects with the distribution grid each year. This will help: (1) refine the engineering and physical processes for 1 to 2 MW solar PV systems interconnections, and (2) reduce the time and cost of implementing such interconnections. SCE will refine the interconnection process by standardizing engineering and design, training specialized labor, and interacting with building and interconnection code agencies as needed to improve efficiency while

still maintaining safety. This supports California's goals as listed in the CEC's PIER[24] Renewable Energy Technologies Program Solar PV Research Plan ("CEC PV R&D Plan") dated September, 2007, of "improving [PV] education, including updating training for solar PV installers, building code officials, architects, and other building personnel. Milestones emphasize the creation and/or improvement of standards for buildings, energy efficiency, and module certification to ensure consistency and high performance."

SCE anticipates initially contracting with owners of large commercial rooftops. Some rooftop owners may not initially see the benefits of solar PV. SCE's initial installations will demonstrate to all large commercial rooftop owners the benefits of utility ownership arrangements and should widen acceptance of similar leases. The important difference between this program and the current third-party ownership with PPAs is that the commercial building tenant (host customer of the PPA) is not a party to the business arrangement. This relieves the commercial building owner from the concern over liability to the solar PV owner about host customer failure to pay for electricity deliveries under the PPA. The utility-owned and leased rooftop business model allows the solar PV facility to deliver electricity directly to the utility. This simplified arrangement will reduce the price of solar PV generated electricity delivered to the grid. Because it is a direct transaction with the utility, it will bypass net energy metering costs.

SCE's Solar PV Program should also expand the number of skilled workers by increasing the total number of PV installations. This expanded number of skilled workers should gain greater efficiency and knowledge simply by repetitively performing installations. Currently, labor is about 20% of the cost of solar PV installations. If the Solar PV Program leads to improving the efficiency of workers, SCE's Solar PV Program should reduce costs of solar PV installation while creating skilled jobs within the State.

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[24] PIER is the CEC's Public Interest Energy Research group which conducts ratepayer funded studies into various advanced technology areas, including renewable energy technologies and environmentally preferred advanced generation.

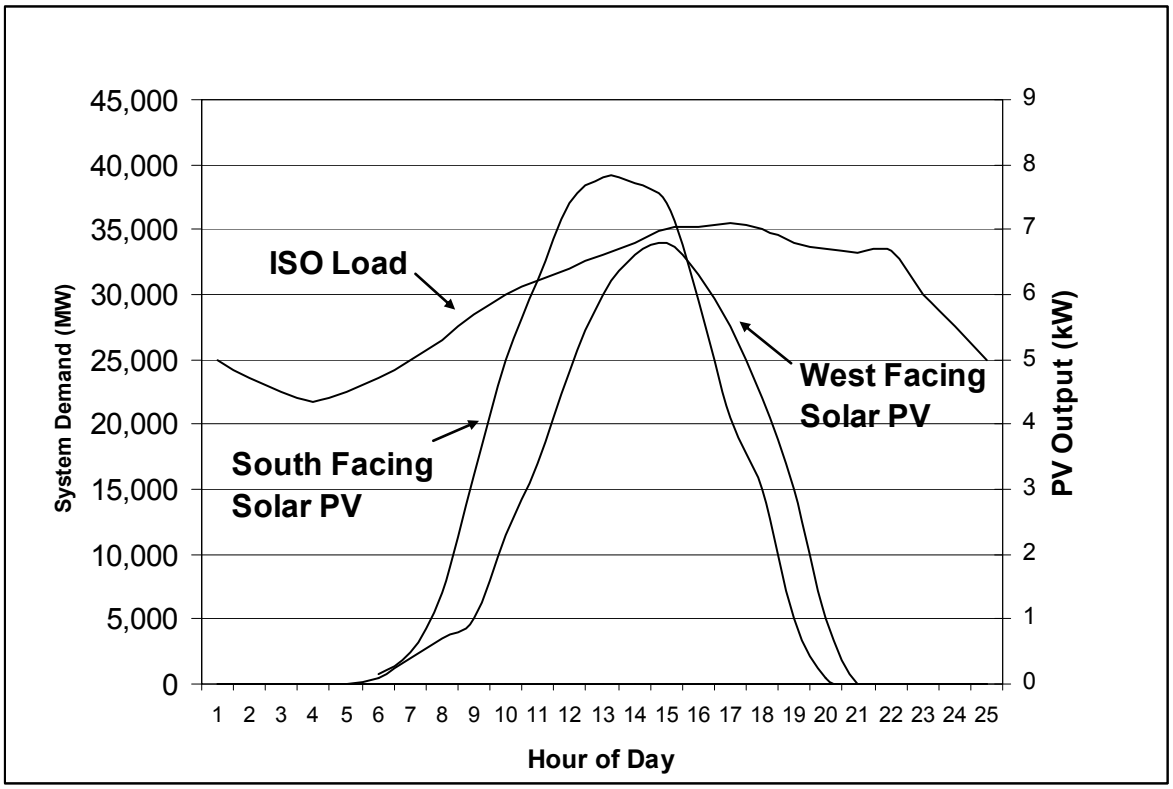
SCE intends to improve the efficiency of the California rooftop solar PV market by increasing the number of 1 to 2 MW solar PV systems. Utilities will also have the opportunity to apply this experience gained in California throughout the United States.

E. The Solar PV Program Will Provide Unique Benefits And Challenges From the Addition Of Large Amounts of Solar PV To SCE's System

Solar PV is a form of distributed generation. As such, it has unique benefits and challenges. SCE will not need to construct new transmission lines to interconnect the distributed solar PV projects contemplated by the Solar PV Program. These systems will interconnect directly with the distribution system. In addition to increasing the amount of renewable energy and reducing greenhouse gas (GHG) emissions, the Solar PV Program should also help determine: (1) how large numbers of these 1 to 2 MW solar PV projects affect the reliability and stability of SCE's distribution grid, and (2) whether such installations can be relied upon to support generation requirements when it is needed, especially on hot, summer days.

Solar PV power may follow the system load better than other intermittent resources. Solar PV energy has historically been higher on clear summer days, which is when the system needs increased generation. Depending on the technology being employed, solar PV output will decrease to a varying degree as temperatures increase. During summer months, higher temperatures might be a deciding factor in technology selection for a given site. Also, as Figure II-1 shows, solar PV power provides significant output when load on SCE's system ramps up. Solar PV does not normally peak simultaneously with load, as load normally peaks in late afternoon when solar PV output begins to decline. As a result, SCE may opt to install some PV systems in a west-facing orientation to maximize the later afternoon output and thus the value to the grid.

Figure II-1
Chart of Solar PV Output vs. Time of Day
Center for the Study of Energy Markets, 2005



Significant amounts of solar PV output will affect the net load profile characteristic for the circuits on which a Solar PV Program facility will be located. This effect on the net load profile characteristics will be an important finding of this program.

SCE can coordinate the Solar PV Program with customer demand shifting using existing SCE demand reduction programs on the same circuit. This will create more fully utilized distribution circuit assets. Without such coordination, much more distribution equipment may be needed to allow solar PV deployment beyond the current Rule 21 guidelines for individual circuits. SCE is uniquely situated to combine Solar PV Program generation, customer demand programs, and advanced distribution circuit design and operation into one unified system. This is more cost effective than separate and

uncoordinated deployment of each element on separate circuits. SCE also can coordinate generation or storage technologies at the substation level to moderate the inherent weather-caused variability in solar PV production before such intermittency cascades into the higher voltage CAISO-controlled transmission system. Such coordination will reduce system costs.

The State's regulatory agencies identified preferred resources in the Energy Action Plan (EAP), in the order of: "energy efficiency, demand response, renewables, distributed generation and clean fossil-fuel."[25] Solar PV is a renewable resource and is a preferred resource under the EAP. The Solar PV Program will be a renewable distributed generation resource.

Solar PV is also a flexible resource. SCE can place solar PV generating facilities in areas where air quality is designated as highly-sensitive by the South Coast Air Quality Management District (SCAQMD), as solar PV has no emissions. Many highly-sensitive SCAQMD areas are also areas with excellent solar resources and significant load growth. SCE expects to place some projects in these highly-sensitive SCAQMD zones both to provide GHG-free renewable energy and to gain valuable understanding of intermittent distributed generation impact on the system.

Solar PV systems typically require little maintenance and have long life times (20-25 years for panels, up to 20 years for inverters). SCE proposes the Solar PV Program as a utility-owned distributed generation project to be developed beginning with start-up in 2008[26] to help meet the Governor's rooftop solar goals without the need to add transmission.

F. The Solar PV Program Will Provide Valuable Information To The State

The Solar PV Program will provide valuable information to SCE and to the State. SCE, as a regulated public utility, is willing to share publicly the results of its experience with solar PV. Specifically, SCE will share information about: (1) how solar PV systems of 1 to 2 MW interact with SCE's distribution system; (2) forecasting and scheduling of solar PV generating facilities of 1 to 2 MW

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[25] D.07-12-052, *mimeo,* p. 2.

[26] Concurrently with the filing of this application, SCE is filing an Advice Letter requesting establishment of a memorandum account for start-up costs. SCE estimates start-up capital costs to be $25 million in 2008. The memorandum account will allow SCE to recover start-up costs to support immediate start-up of work on this program.

disbursed throughout SCE's inland service territory; (3) information about training and availability of the skilled workforce for installation and maintenance of these facilities; and (4) information about potential streamlining and revision of tariff applications, local and state codes, and best installation practices for 1 to 2 MW solar PV projects.

1. Information On Interaction Of Solar PV With The Distribution System

With regard to the interaction of these Solar PV generating facilities with SCE's distribution system, SCE will study the effect of: (1) dependability and availability of generation from the Solar PV Program; (2) the effects of increased amounts of solar PV on distribution circuits; (3) the reaction of Solar PV Program generating facilities to grid disturbances; and (4) the reaction of the grid to Solar PV Program generating facilities' disturbances. To date, solar PV systems installed in SCE's service territory have been smaller than those proposed as part of this project and have not amounted to large fractions of circuit saturation. Such systems have also been net metered because they are customer-owned facilities. This means the actual total solar PV generation is unknown. SCE only knows the net output of these facilities after meeting their customer-owner's load. The large scale deployment of PV under utility ownership will permit SCE to evaluate the efficiency and economics of the generation technologies with precision that is not currently available due to net metering arrangements.

The Solar PV Program generating facilities would export all of their power to the distribution system. The intermittent nature of solar PV systems, especially during partially cloudy conditions, can cause rapid swings in solar facility output. SCE will measure the impact of the solar PV system on distribution circuit voltages, amperage, and other power quality attributes, and, if necessary, will determine the most cost-effective remedial measures.

SCE intends to study how the intermittency of 1 to 2 MW solar PV installations will affect its system. Solar PV power output typically peaks two to four hours before peak system operating

conditions when circuits are most heavily loaded.[27] That being said, solar PV total energy has been highest on summer days when circuits are typically highly loaded.

Solar PV systems are currently set to trip off during high or low voltage excursions. As solar PV becomes more prevalent, SCE may want to keep these systems on-line over a greater voltage range to improve reliable power flow from the solar PV. SCE will gather valuable data to determine new solar PV circuit interruption settings.

2. Information And Experience Forecasting Solar PV Output

The Solar PV Program will give SCE experience in forecasting the output from solar PV generating facilities. SCE will develop advanced weather monitoring and generation prediction models to estimate the energy that will be generated under various weather conditions. SCE will share these models and the underlying data with others.

3. Information On Workforce Training

Because SCE intends to work with a few specialized installation vendors, these vendors can begin to train a skilled workforce on the construction of these types of facilities. In addition, SCE will become acquainted with maintenance practices required for these types of facilities and will begin training a skilled workforce to provide those services.

4. Information On Streamlining Of Tariff Applications For Solar PV

Currently, these larger solar PV installations require individual FERC interconnection tariff applications. With multiple sites being installed, SCE will gain experience on streamlining the FERC interconnection process as well as optimizing system impact studies. For example, answers to questions like, "Is it practical and preferred for small solar PV projects (1 to 20 MW) to be aggregated in the SGIP and CAISO generation queues?" may be answered.

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[27] See Figure II-1 above.

III.

PROGRAM DESCRIPTION

A. Size of Program

SCE proposes to install the Solar PV Program's initial size of up to 250 MW over five years at a base case capital cost of $875 million. SCE's reasonableness threshold for the Solar PV Program is $962.5 million which is the base case estimate plus a 10% contingency. In years one through five, SCE plans to install solar PV systems at a rate of about 50 MW per year. SCE's strategic intent is not to overheat the market for solar PV panels, equipment and installation resources. Based on performance, SCE may seek Commission approval to increase the overall size of the Solar PV Program to a total of 500 MW, likely through a combination of installing more MW per year and lengthening the program. SCE proposes a limited amount of Year 0 activity to facilitate swift start-up of the full-scale program. This activity would setup key systems, processes, personnel, roof leases and system installation for the purposes of program testing and revision only.

The Solar PV Program installation goals are all based on the PV industry convention of using dc output. Unless otherwise specified, the energy output in this filing follows the common convention within the PV industry, which is to refer to output as PV panel dc output. Additionally, the Commission should use the installed dc output in reasonableness reviews because installation occurs in dc panels. Based on sample calculations using the California Energy Commission's ac MW conversion, the conversion factor of 0.90 will be used to convert from MW dc to MW alternating current (ac) (i.e., multiply MW dc by 0.90 to obtain CEC-ac Rating).

B. Length of Program

SCE proposes its Solar PV Program to continue for five years. To facilitate a swift start-up after Commission approval, SCE is concurrently filing an advice letter requesting authority to establish a memorandum account. The memorandum account will record start-up costs for preliminary studies, evaluations, and installation of up to 5 MW of solar PV facilities in 2008. SCE estimates Solar PV Program capital expenditures will total $25 million in 2008. If the Commission has not approved this

application by December 2008, SCE will record its 2009 start-up costs in the memorandum account as well. Specifically, the memorandum account will record costs of the following:

- Leases with building owners
- Identification of the buildings best suited to gain the most knowledge for the preliminary study
- Determination of which technologies to install to gain the most knowledge for the preliminary study
- Engineering plans
- Equipment purchase orders
- Building permits
- Installation procedures/training

Upon approval of the program (requested by year-end 2008), SCE's proposed schedule calls for the initial 250 MW of Solar PV generation to be installed within five years. On average, SCE will install 50 MW per year.

Table III-3 below shows the expected schedule for the Solar PV Program.

Table III-3
Estimated Solar PV Program Schedule

Date	Event
March 2008	SCE files application with the CPUC
April 2008	Commission approves establishment of memorandum account for Solar PV Program start-up activities
April 2008	SCE conducts all necessary preliminary studies and evaluations and installs up to 5 MW of 1 to 2 MW solar PV systems at an estimated capital cost of $25 million in 2008 until larger program approval (requested in December, 2008). If full program approval is not received until 2009, the capital costs may exceed $25 million.
After Solar PV Program approval	SCE will install up to 250 MW of solar PV generation, averaging 50 MW per year

C. Description of Facilities

1. Type of Facilities

Two solar PV module technologies are currently employed by the solar PV industry: (1) crystalline modules, and (2) thin film modules. These two different technologies can be further categorized depending on the materials used to create the cells that convert sunlight into electricity. SCE may install both technologies to compare their effectiveness and costs.

a) Crystalline Technology

Crystalline modules dominate the solar PV market, accounting for approximately 90% of the installed MWs. These large, rectangular modules are seen on most PV installations. The modules are rigid with a surrounding aluminum frame and a protective glass surface.

All crystalline modules use silicon as the primary material for converting sunlight into electricity.[28] When these materials absorb sunlight, the solar energy knocks electrons loose from

[28] Silicon is the same material used by companies such as Intel, AMD and others to manufacture computer chips.

their atoms, allowing the electrons to flow through the material to produce electricity. This process converts light (photons) to electricity (voltage).

Figure III-2
Typical Crystalline Solar PV Module
175 watts measuring approximately
64"x 32" x 1.75" and weighing 33 pounds

Crystalline modules fall into two primary types: (1) multicrystalline; and (2) monocrystalline. These terms refer to the type of silicon formulation of the individual *cells* that generate the current inside the module. Simply stated, raw silicon is used to create ingots which are then sliced into thin wafers. These low wattage wafers, or cells, are then wired to each other to increase their output. Figure III-2 shows seventy-two black cells wired to each other and sandwiched between a sheet of tempered glass on top and a protective backing on the rear. The tempered glass makes for a robust product that is impervious to all but the most extreme weather conditions (baseball size hail might damage a module) and normal hazards. An aluminum frame surrounds the glass for mounting purposes.

Monocrystalline modules are generally more efficient and more expensive to manufacture than multicrystalline modules. This increases the cost of the module. Just like light bulbs,

crystalline modules are available in various wattages. The size of the module will vary depending on its wattage and other factors.[29] Crystalline modules require a mounting structure, typically referred to a *rack*, to support it on the roof. Generally, crystalline module warranties are 20-25 years, depending on the manufacturer.

b) Thin Film Technology

Thin film modules fall into two broad categories: amorphous and rigid. Unlike crystalline modules, amorphous thin film use significantly less silicon than crystalline modules and a few other thin film technologies use no silicon to generate electricity.

Figure III-3 below shows that a flexible amorphous thin film modules are flexible panels that can be applied to curved as well as straight surfaces. These modules are manufactured with multiple layers of semiconductor materials that are only a few micrometers thick. These layers are attached to a flexible metal backing called substrate, through a spray-on process. The outer nonconductive layer looks like rubber. Flexible amorphous modules are usually attached to a metal roof known as a *standing seam roof.* An adhesive is applied to the rear surface of the module at the factory. Installers remove the plastic protection to expose the adhesive. The module is then rolled onto the standing seam roof. As these modules have no frame, unless the roof is a standing seam roof, amorphous modules may not be practical for rooftop applications.

[29] Solar modules are rated using both national and international standards. This means a 100 W rated module will produce 100 W but its actual physical dimensions and mounting arrangement vary by manufacturer. Solar modules are not a standard physical size, such as a 4 foot by 8 foot piece of plywood.

Figure III-3
Typical Amorphous Thin Film Module
Measuring 18 feet long by 15.5" wide
and Weighing_17 lbs.

Rigid thin film modules generally utilize different materials than amorphous and crystalline modules. Technologies include cadmium telluride (CdTe) and Copper Indium Gallium Selenide (CIGS). As with flexible thin film modules, a rigid thin film module has multiple layers of semiconductor materials. These layers are attached to a rigid substrate using the same spray-on process as an amorphous module. A tempered glass top protects the assembly. Pricing for these modules is significantly lower than any other commercially available PV module, but they have a lower efficiency than crystalline modules. Consequently, they are usually marketed towards large scale ground-mount systems for the utility market sector or are installed on very large rooftops where space is not a factor. Like crystalline modules, rigid thin film modules require a rack to support them. Generally, warranties on thin film modules are 25 years. Figure III-4 below shows a rigid thin film module.

Figure III-4
Typical Rigid Thin Film PV Module
Measuring 4 feet long by 2 feet wide
and Weighing 26.5 lbs.

SCE expects to see a new generation of thin film modules in the coming years based on a new generation of materials that is not currently commercially available. The markets these modules will serve (residential, commercial, utility) are not known.

c) Technology Comparison

There are tradeoffs when comparing crystalline and thin film technologies. Crystalline technology modules generate more power on a W per square foot basis than non-crystalline technologies. Although the numbers vary slightly from manufacturer to manufacturer (and from product to product within each manufacturer's offering), a crystalline module will generate approximately 12.3 W/sq ft. In contrast, at less than 6 W/sq ft., flexible amorphous modules have about half the efficiency of crystalline modules. Rigid thin film modules generate approximately 9.5 W/sq ft. Currently, thin film modules are less expensive than crystalline modules. Thin film modules require extra materials and labor to install as more modules are required to achieve the same system wattage as a system using

crystalline modules. If roof space is not an issue, thin film modules might be the preferred technology for a solar PV system. In addition to the lower module cost, thin film modules perform better than crystalline modules in low light, or diffuse lighting, conditions. So, they will generate more power on cloudy days. They also generate power earlier in the morning and later into dusk. All module technologies "derate" in hot weather, meaning as they get hotter, they become less and less efficient. Thin film modules derate less than crystalline modules. Therefore, thin film technology might be the preferred technology in certain southern California locations.

d) Inverters and Balance of System

All solar PV modules, regardless of technology, generate dc power. SCE must convert this dc power to ac power to use in its distribution system. Inverters perform this conversion. Figure III-5 depicts a 500 kW ac inverter. The inverter can be configured with custom software to be remotely controlled. This would allow SCE to change the system output based on circuit loads or weather conditions. Inverters are rated in ac. Inverters are available in various sizes from a few small kilowatts (kW) ac for residential solar PV systems to 500kW ac for large systems. Manufacturers are currently designing inverters above 1 MW ac.

Figure III-5 shows a 500kW ac inverter and transformer.

Figure III-5
500kW ac Inverter and Transformer
Inverter measuring 7.6"x9.6'x3'6" (HxWxD) transform measuring 5'x4'x4' (HxWxD) and weighing combined approximately 9,800 pounds.

Inverter ***Transformer***

Solar PV systems also include conduit, wire, dc and ac disconnects (safety devices to turn off or isolate parts of the system), and combiner boxes. Modules are wired together in series (imagine multiple batteries in a flashlight) into "strings." These strings can vary in number from 6 to 18, depending on a number of factors (module type and lowest temperature one might see at the project location). These larger string quantities enter boxes located throughout the array and are then "combined" into a smaller number of parallel wires that are then wired into the inverter. All of the items in a solar PV sytem other than the modules are commonly called Balance of System (BOS) components.

e) PV Module Mounting Systems

Except for flexible, amorphous thin film modules, all solar PV systems require some type of attachment method. This product is typically called a *rack.* There are two main categories of racks: penetrating and non-penetrating. Non-penetrating racks are further defined as ballasted (requiring some weight to be added to the rack besides the modules) or non-ballasted (primarily relying

on the weight of the rack and modules themselves to hold the array in place). SCE does not plan to use penetrating racks in the Solar PV Program to minimize the probability of roof leaks.

Non-penetrating racks are precisely as the name implies. The rack sits on top of the roof. Ballasted systems require the use of weighted material such as cinder blocks or pavers to keep the array in place. These systems add a significant amount of weight to the array. The total weight of ballasted systems, including modules, can reach 8 pounds per square foot and most commercial roofs cannot support this weight. Non-ballasted systems rely on the weight of the array itself to keep them in place and typically weigh 3-5 pounds per square foot, including modules. For an installation subject to high wind conditions an adhesive material (Sika or M1), ballasting material, or a combination of both, might be required at the edges of the array. The manufacturer of the rack will typically specify what is required to assure the PV array will meet local building department codes for anticipated winds. A local structural engineer will then confirm these calculations.

Figure III-6 is a non-penetrating rack adhered to the roof with M1 adhesive. The modules on the left side are in their normal operating position. The module is about 1 foot above the roof at its highest point. The right photo shows 1 row tilted to allow access to the wiring underneath the modules and to the roof for maintenance. Thin film modules are usually not tilted. They are installed parallel to the roof and are less than 1 foot off the roof surface.

Figure III-6
1.2 MW Non-Penetrating Solar PV
System on Commercial Rooftop in Sacramento, CA

f) Building Integrated PV

The state of California is committed to promoting the use of Building Integrated Photovoltaic (BIPV) products on new buildings. As evidence of this, the aforementioned CEC PV R&D Plan states that the goals of their program include: ". . . identifying synergies between PV and energy efficiency by 2008 and achieving widespread penetration of BIPV products by 2017. These milestones will provide improved performance, ease of use, and economics of PV systems, thereby supporting CSI and SB 1." There are an extremely limited number of BIPV installations worldwide to date. SCE's program will test and encourage this type of installation. Developers may only focus on existing roofs as they are the cheapest installation.

A key benefit SCE can bring to this effort is coordination between the various elements of Demand-Side Management (DSM). SCE's New Construction Services (NCS) group is an in-house team of technical specialists in energy efficiency (EE) and sustainable design. NCS is responsible for delivering SCE's commercial new construction EE offerings to building owners, developers, architects, and engineers. One way NCS delivers these offerings is by building and maintaining relationships with specific developers. As a result, NCS can review and analyze all of a developer's planned projects for EE opportunities. SCE is working to expand NCS's offerings to new construction

projects to include on-site renewable energy incentives, electric transportation (particularly for fork-lift operation), and demand response capabilities.

Large customers, also have assigned account managers through our Business Customer Division (BCD), who are the single point-of-contact through all of their dealings with SCE. This ensures continuity of service, and refers any eligible EE projects to the appropriate program. Similarly, because of ongoing relationships with owners and design teams in particular, many projects referred to NCS cover improvements to current building stock. For program purposes, SCE divides gut remodels (considered new construction) from simple equipment swap-outs (considered retrofits). NCS refers any such projects to either Standard Performance Contracting (SPC) or Express Efficiency, depending upon the scope of the retrofit.

However, one challenge to working with large customers that operate as landlords (often through property management firms), leasing commercial real estate to tenants, is that the tenants pay the utility bills. SCE may not have identified the landlord through our BCD. If SCE was not involved in the construction of the facility, it may not have a relationship with the actual owner. As large customers that operate as landlords buy and sell properties, often with the express intention of retaining lucrative tenants, this becomes an additional challenge.

A key part of the effort to integrate DSM services is the emphasis upon the CPUC's loading order: invest in cost-effective EE (and demand response) first and only then meet the remaining load with renewables. SCE would also work through CSI group to make sure that any projects (including warehouses) pursuing PV had been contacted by their BCD account manager to discuss opportunities for DSM.

SCE can leverage this delivery model to great effect with the large customers that lease commercial real estate to tenants in our service territory. This will enable SCE to pursue additional improvements in EE in commercial buildings even if they are not suitable candidates for the Solar PV program.

2. Size of Facilities

Rooftop arrays vary in size depending on the PV module technology being used and whether it is a tilted or flat array. Crystalline modules typically tilt toward the south and thin film modules are usually flat mounted.

Tilted arrays require more roof space than flat arrays because there must be adequate space between each row of modules to keep them from shading the adjacent row. An array with a 5 degree tilt will require less space between rows than an array with a 20 degree tilt. A flat array only requires enough space between module rows to allow a technician to walk between them for maintenance. Generally, a 1 MW array employing crystalline modules will require 125,000 square feet of roof space. A 1 MW rigid thin film array will require 175,000 square feet of roof space. A 1 MW flexible amorphous thin film array will require 230,000 square feet of roof space. These numbers include space required for conduit, combiner boxes, and other BOS components associated with the array. The required roofspace could increase depending on other roof protrusions they could potentially shade the modules or prevent a module from being installed. A protrusion is defined as anything on the roof (i.e., air handlers, skylights, vents, or drains). Protrusions could substantially impact the required roof space to prevent module shading from the object. For example, an air handler that is 8 feet tall should have 16 feet of clearance to the closest module that could be shaded.

None of the module technologies are visible from street level. The combination of building height, minimal height of the array above the roof, and setback of the array from the edge of the roof (usually 3 feet) all contribute to it being hidden. Also, for safety reasons, many buildings have a parapet around the building that also serves as a blind for existing equipment such as air handlers.

Figure III-7 is a street level photograph of the solar PV system on the rooftop of the Long Beach Convention and Entertainment Center in Long Beach, CA. There is a 1 to 2 foot parapet surrounding the rooftop, and the array is set back from the roof edge by around 3 feet.

Figure III-7
Photograph of the Long Beach Convention and Entertainment Center illustrating the solar PV array is not visible from street level

Inverters vary in size depending on the model. A single 1MW inverter dimensions are double that of a 500kW inverter. Typical 1 MW transformer dimensions are 9'x8'x5' (HxWxD) for an air-cooled transformer. Oil-cooled transformers are smaller than air-cooled transformers.

Inverters are typically located inside the building in an electrical room. If such a room is not available, the inverter(s) can be located outdoors next to the building. It is desirable to locate it as close to the array as possible to minimize power loss due to long wire runs. Inverters are designed to be installed outdoors. So, no additional enclosed building is required to house them. It is preferable to locate inverters in areas with less sun or inside a shade structure in hot, sunny locations. This is because heat can degrade inverter performance.

3. Location and Configuration of Facilities

SCE's Solar PV Program will study the appropriate locations of the 1 to 2 MW solar PV installations. SCE will develop methods to determine the optimal location for the PV installations. SCE will consider: (1) quality of the local solar resource (estimate of expected PV generation based on

factors such as expected cloud/fog cover, haze and smog, ambient temperature, and geographic latitude) and other meteorological data, (2) roof capacity and other building attributes, and (3) local circuit concerns.

To determine the quality of the local solar resource, SCE will rely on the National Renewable Energy Lab (NREL) database that provides information down to 10 km grids. By choosing the best combinations of available roof-site location and local solar resource, SCE will optimize the output of the solar PV installations. SCE will also consider other meteorological data. For example, high wind areas may preclude certain solar PV panel attachment methods. Crystalline solar PV panel performance degrades under high temperature conditions. So, more moderate temperature zones may be more desirable than very hot desert regions for this technology. To assess the impact of various solar quality areas, SCE may also install solar PV in poorer solar areas, such as those affected by the regional "June Gloom" (severely overcast). SCE will, then, quantify the effects on solar PV output of location, the resulting impact on the grid, and the implications for sizing back-up power (at the substation) or required demand response (from customers on the affected circuit).

In terms of roof capacity and other building attributes, SCE will take into account the following variables:

(1) Roof Capacity – Depending on the module technology being employed and roof protrusions, each roof must have available up to 250,000 square feet of available space per 1 MW installation.

(2) Roof Loading - Roofs must handle the additional weight loading which can vary based on technology as well as the individual vendor's panel weight. In general, the roofs must hold an additional 3 to 5 lbs. per square foot.

(3) Shading and orientation –Roofs should have little to no shading and be oriented to achieve the desired solar PV panel output profile. Normally, this means a south-facing exposure, as this orientation maximizes overall output of the installation. SCE may also consider a west-facing exposure to increase late afternoon sun which is more coincident with system load.

(4) Building Electrical Loads – SCE will identify buildings that have the size and structural strength to accommodate 1 to 2 MW and would not be typical candidates for net energy metering. For example, a large warehouse roof with little on-site load.

(5) Ground space requirements – SCE will need 100 to 200 square feet of ground space (indoors or outdoors) to install the inverters and transformers as these are typically too heavy to install on a roof.

(6) Contractual and other concerns – The conditions for leasing the roof and roof access are of key concern. The ease of local permitting may also play a role in determining the location of the facilities.

4. Interconnection Facilities

Figure III-8 illustrates typical interconnection facilities for a rooftop solar PV project. The figure shows a single line diagram for an existing distribution circuit (Box A), existing customer service (Box B), and the proposed new service for solar PV projects (Box C).[30] The simplest interconnection utilizes an existing transformer located on the customer's property shown as a 12kV/277-480 Transformer in Figure III-8. Interconnection facilities include a new line from the existing transformer shown in Box B, to a new utility panel housing a meter and a disconnect switch shown in Box C. The utility panel also functions as an interconnection point to connect the output wire lead from the solar PV generation facilities into a utility electrical panel. SCE's preferred interconnection includes a visible disconnect switch so utility workers can readily identify where to manually isolate solar PV generation from the rest of the electrical grid. SCE is also pursuing the ability to isolate the solar PV generator from the grid using remote signal to the inverter.

Figure III-9 shows a simplified interconnection utilizing an existing transformer. Some customer locations may not possess such a transformer. Therefore SCE anticipates adding a transformer as part of the interconnection facilities. Figure III-9 shows a more complex interconnection because it includes a new transformer and pad mounted switch. Looking at Box C in Figure III-9, the

[30] A single line diagram shows one phase of a three phase electrical system. An actual installation would include three wires where one is shown, but not three transformers or switches as those devices accept three phases of electricity.

interconnection facilities consist of a wire from the existing transformer in Box B to a new pad mounted electrical switch (shown as PME-11) in Box C. From there, a cable connects the pad mounted switch to the new transformer. The remaining facilities are similar to those shown in Figure III-8; namely a wire from the transformer to a new utility panel housing a meter and a visible switch. This box connects the wire lead from the solar roof top generation facilities into a utility electrical box.

Combined, Figures III-8 and III-9 illustrate the range of interconnection options SCE expects to use in the Solar PV Program. These figures illustrate simple and conceptual interconnections. Actual interconnections may vary on a case-by-case basis.

Figure III-8
Proposed System Single Line
Simplified Interconnection

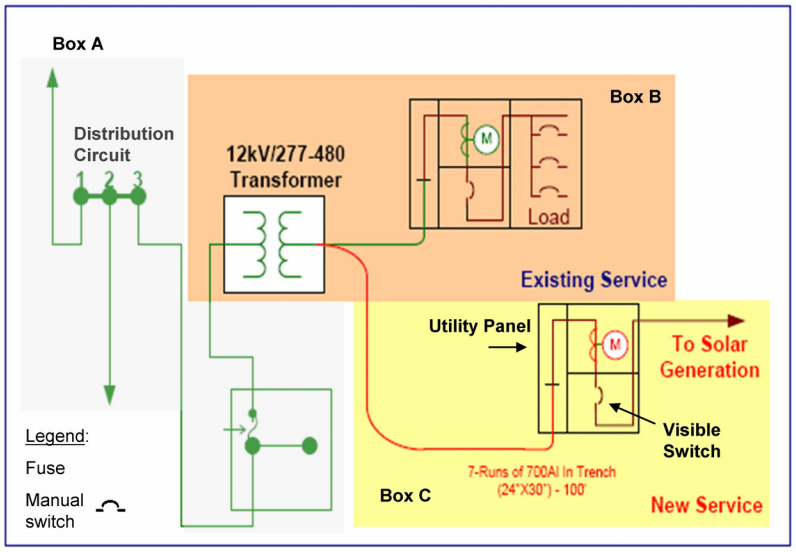
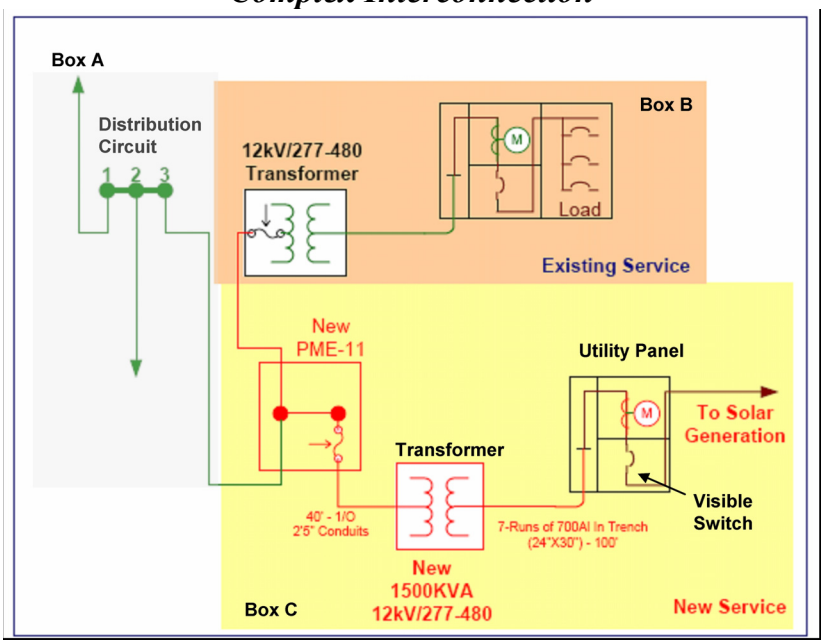


Figure III-9
Proposed System Single Line
Complex Interconnection



5. Data Acquisition System (DAS)

The DAS will gather operating data at each site. This data can provide valuable information regarding the energy quantity and quality output of the PV systems tested. The DAS will

include weather sensory equipment that will enable SCE: (1) to compare the actual output with projections from computer generated models, and (2) to evaluate the impact of weather conditions experienced on the quantity and quality of power output.

Any generating station connecting to the CAISO Grid must enter into a Meter Service Agreement (MSA) with the CAISO. The CAISO requires certain operational data be supplied to them on an ongoing basis as part of interconnecting generation to the electric grid. The DAS systems will collect and send this data to the CAISO real time.

All generation connected to the CAISO grid must forecast and schedule power into the CAISO system on an hourly basis. Currently an intermittent technology such as solar PV would participate in the CAISO's PIRP. However, the PIRP currently only schedules wind resources. SCE will work cooperatively with the CAISO and others to formulate the requirements for solar PV to join the PIRP. For a generation facility not in PIRP, the generation forecast is due nearly 3 hours ahead of the actual generation period. This is a challenging task for solar PV generation. As a part of this project, SCE will identify predictive weather methodologies, such as cloud movement to attempt to forecast output of these PV systems for the CAISO 3 hours ahead until implementation of the PIRP requirements for solar PV.

SCE will install all components between the inverter and the point of delivery to the grid. The DAS components are forecast to cost approximately $200,000, for each 1 to 2 MW solar facility, as follows:

- Meter $10,000
- Communications $45,000
- Data collection $40,000
- Weather station $55,000
- Auxiliaries $50,000

6. Leasing Rooftop Space For Facilities

The success of the Solar PV Program is in large part dependent upon securing appropriate lease agreements with building owners/developers. As noted above, SCE intends in the first phase to

install up to 250 MW of solar PV on commercial building rooftops at various locations within SCE's service territory. The proposed 1 to 2 MW installation per location will require up to about 250,000 sq. ft. of rooftop space. For this Solar PV Program, SCE anticipates that it will look to a limited number of building owners/developers to provide appropriate location inventory in order to more efficiently select appropriate locations and limit the number of simultaneous lease negotiations.

Upon the selection of appropriate locations for the PV Facilities, SCE intends to enter into negotiations with the owner/developers of those sites in order to secure a mutually agreeable rooftop lease. Because the large-scale installation of utility-owned rooftop PV systems is a relatively novel concept, the Solar PV Program will allow SCE to gain valuable experience regarding certain rooftop lease business deal points such as optimal lease terms, appropriate rental rate structures, reasonable site access requirements. In every instance, however, SCE will negotiate to secure appropriate and reasonable clauses to ensure appropriate allocation of the rights and obligations of SCE and the respective owner and protection of ratepayer interests.

SCE may also opt to locate a few 1 to 2 MW installations on utility-owned roofs as well.

IV.

PROGRAM COST ESTIMATE

A. Capital

1. Generating Facilities Cost

Table IV-4 below provides estimated costs for a typical 1 MW project. Due to the volatile price of petroleum and copper, wire distributors will only quote pricing for 30 days. Table IV-4 projects average shipping costs which can vary depending on the actual locations of the solar PV facility.

Table IV-4
Estimated Hardware Cost for 1 MW Solar PV Project
(2008$)

Hardware	Cost
PV System (Module, Rack, Balance of System)	$2,540,275
Data Acquisition System (DAS)	$ 200,000
Interconnection Equipment	$ 150,000
TOTAL HARDWARE COST	$2,890,275

2. Installation Cost

Table IV-5 provides estimated installation costs for a typical 1 MW project. On-site installation costs can vary substantially based on labor rates in effect at the time of the installation.

Table IV-5
Estimated Installation Cost for 1 MW Solar PV Project
(2008$)

Labor Activity	Cost
Site Selection	$ 3,000
Engineering	$ 35,000
Permits	$ 10,000
Installation and Commissioning	$461,725
Project Management	$100,000
Total	$530,200
TOTAL LABOR COST	$609,725
$/W	$ 0.61

Assuming computer-based or hard copies of drawings do not exist, a survey will be made of the rooftop before the array layout can begin. This is in addition to an initial site walk of the building. Once the engineering drawings are completed, the roof must be marked for the array layout.

Delivery of modules, inverters, rack hardware, and Balance of System (BOS) components includes the process of lifting the equipment to the roof with a crane and locating it throughout the roof to distribute the weight. The delivery schedule can be modified to minimize disruption to the customer. This could either be a compressed schedule of trucks making deliveries to a staging area next to the crane while personnel lift product to the roof (more disruption over a shorter duration), or activities can be spread out to minimize traffic (less disruption over a longer duration).

Once all materials have been placed on the roof, installation of the array can begin. During this phase of the installation, impact to the daily operations of the building activities are minimal and are primarily associated with letting installation personnel onto the roof and closing roof access at the end of the day. The building lessee's security procedures could increase the length of the installation

period. Vehicles on site are primarily those associated with workers commuting to the site. Additional disruption is possible due to trench work required to tie-in the inverter to the SCE circuit. Commissioning is the process of turning on the system, testing and notation taking, and troubleshooting any problems.

Total on-site installation time is approximately 30-45 days for a 1 MW project. However, the time for completion of the first project after regulatory approval is about 4-6 months due to lead times to order the modules and inverters.

3. Interconnection Costs

Interconnection costs range from about $70,000 for simple installation to $150,000 for the more complex installation (in 2008$). The main difference in costs between the two types of installations is the addition of a new distribution transformer and pad mounted switch. These estimated costs assume a reasonable distance of new distribution cable (100 feet), which if longer or shorter could increase or decrease costs respectively. Cable costs assume underground installation. These cost figures illustrate simple and conceptual interconnections. Actual interconnection costs may vary on a case-by-case basis.

The proposed Solar PV Program would apply for interconnection service pursuant to SCE's Wholesale Distribution Access Tariff (WDAT) for each site using the Small Generator Interconnection Process (SGIP), just as any other non-SCE generation project is required to apply for such service. SCE expects the cost of each interconnection to range from $1,500 to $9,000 depending if the interconnection is applicable for the WDAT's fast track process or normal track process.

4. Total Program Capital Costs

SCE proposes to install up to 250 MW of PV generation within 5 years at a base case cost of $875 million. The overall base case cost of the Solar PV Program averages $3.50/W, including $2.89/W of material costs and $0.61/W of labor costs. SCE's proposed reasonableness threshold is $962.5 million which is the base case amount plus a reasonable 10% contingency. The reasonableness threshold cost of the Solar PV Program averages $3.85/W. Table IV-6 summarizes the capital cost of the Solar PV Program per year.

Table IV-6
Summary of Capital Costs of Solar PV Program
(2008$)

Year	Capital (Million$)	MW Installed	Estimated Time Frame
0	$25	5	April '08 to Dec '08
1	$174	50	2009
2	$174	50	2010
3	$174	50	2011
4	$174	50	2012
5	$154	45	2013
Total	$875	250	

Though the Solar PV Program estimates a base case total installed cost of $3.50 per watt, the average cost of installation will vary from year to year. The costs incurred during the start-up phase of the program (listed as year "0") are estimated to be $25 million for up to 5 MW of installed PV generation, which produces an average installed cost of $5/W (2008$) for that year. The increased average cost is higher in the first year because of:

- Contact Development / Procurement – SCE will work with PV manufacturers and installers to develop agreements which is labor intensive.
- Site Evaluation and Selection – SCE Distribution Field Engineering will locate and evaluate the best locations to install PV to maximize grid benefits.
- Data Monitoring – SCE will install additional data monitoring equipment on the initial installations to better evaluate performance.
- Process Optimization and Optimization – SCE will use the start-up phase to gain knowledge and develop optimal process for interconnection and installation.

Beyond Year "0", SCE estimates the cost per installation to remain constant at $3.48/W (2008$). Once SCE standardizes the processes and contracts in the start-up phase, the individual

installation costs will remain stable in constant dollars. Individual project cost will vary due to locational issues (permitting, ease of installation), but the average costs should remain fairly stable. SCE assumes 50 MW of solar PV installed per year for years 1-4 resulting in a annual capital expenditure of $174 million. SCE assumes 45 MW of solar PV installed in year 5 at an average cost of $3.42/W ($2008). The total capital expenditures for year 5 are forecast to be $154 million.

B. Operation & Maintenance Cost

1. Roof Lease Payments

The leasing of roof space for PV panel installations is a novel concept. No real market reference pricing currently exists. The Solar PV Program differs from most large-scale rooftop PV deployments. This program will be for large roof buildings that would not otherwise be typical candidates for net energy metering. The closest business model is the rooftop cell phone tower installations. But even these are not representative, as they occupy a much smaller area of the roof.

SCE is engaged in discussions with numerous Real Estate Investment Trusts which own large numbers of commercial buildings, to determine mutually equitable arrangement for leasing roof-space. SCE is exploring multiple options to establish a market price, such as leases based on a square foot basis and those based on a percentage of gross power output value. Other issues, such as liability minimization, roof access, lease term, etc., are also being examined to determine acceptable contracting terms.

As this is a new opportunity for the large rooftop owners, it is difficult to estimate the expected leasing rates. SCE realizes that the maximum price paid for these roof leases must be kept to a small percentage (equal to or less than 10%) of the value of the electricity being produced.

SCE has identified numerous potential leasing partners whose portfolios contain several times the amount of roof space needed for even the 500 MW program. SCE is confident that the leasing issues can be adequately addressed to the satisfaction of both parties and that, ultimately, ample cost-effective roof leases can be arranged.

2. Maintenance Cost

Preventative maintenance costs are typically low for solar PV systems. Generally, maintenance consists of washing the modules once or twice each year to facilitate maximum energy production. The frequency could vary depending on specific site conditions. Regularly monitoring the system output through the DAS will provide the necessary information to determine when cleaning is required. A visual inspection of the array once a year is also usually recommended and can be performed at the same time as a routine cleaning. Inverters do not typically require routine maintenance other than to make sure the air filters are clean. If the inverters are installed indoors, a yearly visual inspection should suffice.

Table IV-7 contains an estimate of annual O&M costs, not including the roof lease for a 1 MW solar PV project of $35,000 (2008 $). The Solar PV Program would add up to 50 such projects each year, increasing O&M by $2.626 million per year.

Table IV-7
Estimated Yearly O&M Costs for a 1 MW Solar PV Project
(2008$)

Labor Activity	Cost per Year	Frequency
Array Cleaning	$ 10,000	2x per year
Array Inspection	$ 5,000	1x per year
DAS Monitoring	$ 20,000	Monthly
TOTAL O&M COST PER YEAR	$ 35,000	

3. Staffing

The Solar PV Program will require a staff of 11 Full Time Equivalent (FTE) employees. If the Commission authorizes SCE's Solar PV Program, SCE's current staffing level is insufficient to provide adequate oversight and project development capability.

Table IV-8 summarizes the costs associated with the required additional employees.

Table IV-8
Solar PV Program Management Labor Forecast Increase For New Employees
(2008$)

Line No.	Incremental Staffing:	# Positions	Total Labor Increase
1	Manager - Project/Product 2	8	$ 1,029,768
2	Manager 3	1	$ 163,296
3	Technical Specialist 3	2	$ 199,710
3	Total Increase in Labor	11	$ 1,392,774

These employees will provide the project management and program contract oversight necessary for the Solar PV Program. The employees would include senior management, technical specialists, and senior project managers including:

- **Vendor Relationship Management** – Responsible for managing rooftop, panel and supplier relationships. Will have the contact management function. Ongoing primary point of control for all vendors, contracts, and internal SCE interactions. Two Manager-Project/Product 2 positions for the six years of the program.
- **Site Management** – Responsible for site selection, coordination, and interconnect management. Primary point of contact during "pre-installation" phase. Works to assure prompt interconnect activity and permitting coordination. Two Manager-Project/Product 2 positions for the six years of the program.
- **Installation Management** – Responsible for managing the installation process through Engineer, Procure, Construct (EPC) Vendor, or multiple contractors. Executes site management's plan. Two Manager-Project/Product 2 positions for the six years of the program.
- **Business Management** – Responsible for planning, strategy, reporting and management of department and project budgets, staff, regulatory reporting and

other activities. Two Manager-Project/Product 2 positions for the six years of the program.

- **Operations** – Responsible for project maintenance and monitoring. One Manager 3 and two Technical Specialist 3 positions beginning in year 2 of the program. In addition, the Manager 3 will have management responsibility for the program staff.

Table IV-9 below summarizes the proposed staffing costs each year. The dates listed assume approval of the memorandum account in April, 2008.

Table IV-9
Forecast Summary of Staffing Costs of Solar PV Program

Year	Labor (2008$)	Estimated Time Frame
0	$737,514	April '08 to Dec '08
1	$1,290,419	2009
2	$1,392,774	2011
3	$1,392,774	2012
4	$1,392,774	2013
5	$1,392,774	2014

V.

RATEMAKING

A. Introduction

This chapter presents SCE's cost recovery proposal for the Solar PV Program. SCE is requesting recovery of the revenue requirement associated with the costs associated with Solar PV Program activities described in the previous chapters. SCE expects to incur approximately $53.8 million (2008$) in O&M and $875.0 million (2007$) in direct capital expenditures over the 2008 through 2014 program period, and requests that the Commission find reasonable up to $962.5 million (2008$) in direct capital expenditures during the 2008 through 2014 program period.

B. Forecast of SCE's Solar PV Program Revenue Requirements

Table V-10 below, contains the estimated annual revenue requirements during the 2008 through 2014 period.[31]

[31] The revenue requirement shown for 2008 will be recovered from customers in 2009 along with the estimated 2009 revenue requirement.

Table V-10
Summary of Solar PV Program Estimated Revenue Requirements
(O&M and Capital Costs)
Thousands of Dollars

Line No.	Item	2008 1/	2009	2010	2011	2012	2013	2014
1.	**Operating Revenues**	**3,497**	**28,148**	**66,809**	**102,374**	**135,238**	**164,573**	**169,670**
2.	**Operating Expenses:**							
3.	O&M Expense	1,000	4,294	7,311	10,401	13,659	16,809	17,319
4.	A&G – Benefits	298	536	596	614	632	651	671
5.	Uncollectible Expense	8	63	150	230	304	370	382
6.	Franchise Requirements	32	251	597	914	1,208	1,470	1,515
7.	Depreciation	547	6,734	17,044	27,566	38,316	48,750	53,562
8.	Taxes Other Than Income	0	125	1,285	3,211	4,899	6,427	7,711
9.	Taxes Based On Income	726	5,138	12,347	17,670	21,616	24,715	23,292
10.	Total Operating Expenses	2,612	17,142	39,331	60,605	80,635	99,192	104,452
11.	**Net Operating Revenue**	**886**	**11,006**	**27,478**	**41,769**	**54,603**	**65,381**	**65,218**
12.	**Rate Base (Average)**	9,095	112,882	281,823	428,401	560,026	670,579	668,906
13.	**Rate Of Return**	9.75%	9.75%	9.75%	9.75%	9.75%	9.75%	9.75%
1/ The 2008 annual revenue requirement has been prorated assuming an effective date of April 1, 2008.								

Beginning in 2009, SCE requests to include in generation rate levels, and recover from bundled service customers, the forecast Solar PV Program revenue requirement each year until this revenue requirement is included in SCE's GRC revenue requirement.[32] As discussed in more detail below, differences between the Solar PV Program-related generation retail revenue and the actual recorded Solar PV Program revenue requirement based on recorded costs (i.e., over- or under-collection) will be

[32] It should be noted that by paying for these costs, SCE's bundled service customers would see a reduction in their energy procurement costs reflected in SCE's Energy Resource Recovery Account (ERRRA) revenue requirement because SCE would not need to procure the equivalent amount of energy from other sources.

recorded in the SPVPBA. SCE will also include the estimated above market cost of the annual revenue requirement in the calculation of the vintaged Cost Responsibility Surcharges (CRS) applicable to Direct Access, Departing Load and Community Choice Aggregation customers each year.[33]

If as discussed in Chapter I, the Solar PV program is successful, SCE may seek additional authority to expand the program to 500 MW. In the request to expand the program, SCE will include its proposal to continue to use the SPVPBA during the expansion period.

1. Capital Expenditures/Additions

For purposes of estimating the annual revenue requirements contained in Table V-10 above, SCE used the direct capital expenditures estimated to be $875 million in constant 2008$ shown in Table IV-6. Table V-11 shows the estimated direct capital expenditures for each calendar year, plus escalation based on the index discussed in Section D below, plus an adder to estimate overheads such as, Allowance for Funds Used During Construction (AFUDC), capitalized pensions and benefits, payroll and property taxes.[34] The total estimated nominal expenditures in the amount of $1,028.0 million are included in forecast plant-in-service (i.e., rate base) as of the date the plant investment is estimated to go in service.

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[33] Currently, the Commission authorizes the CRS rates in SCE's annual ERRA Forecast Proceedings.

[34] SCE will not include capitalized A&G on recorded capital expenditures included in the SPVPBA.

Table V-11
Summary of Solar PV Program Calendar Year Capital Expenditures
$millions

Col. A	Col. B	Col. C	Col. D	Col. E	Col. F
Year	**MW**	**Direct Expenditures ($millions)**	**Escalation ($millions)**	**Overhead Adder ($millions)**	**Total Expenditures ($millions)**
2008	5	25.0	-	2.5	27.5
2009	50	174.0	3.7	17.8	195.5
2010	50	174.0	7.4	18.1	199.5
2011	50	174.0	11.4	18.5	203.9
2012	50	174.0	15.6	19.0	208.6
2013	45	154.0	21.4	17.5	192.9
2014	-	-	-	-	-
Total	250	875.0	59.5	93.5	1,028.0

2. Depreciation Expense

Table V-10 estimates the total depreciation expense during the 2008 through 2014 period to be $192.5 million. For purposes of estimating depreciation expense, the capital costs are divided into five categories: (1) PV Modules and Balance of System Components; (2) PV Rack; (3) General; and (4) Distribution. Each of these categories are explained below along with the estimated depreciable lives, net salvage requirements, and resulting depreciation rates.

a) Generating Facilities Plant

(i) PV Modules and Balance of System Components

These assets include the PV modules that convert sunlight into electricity, the inverter to convert dc to ac to use on SCE's distribution system, and the balance of system components not in other categories. Chapter III, Program Description, Section C, Description of Facilities describes these assets in detail.

The warranties of the solar PV modules range from 20-25 years depending on the manufacturer. Most warranties are limited and simply cover loss in power due to defects in workmanship or materials. When developing a depreciable life for plant assets, however, there are

many other forces of retirement to consider in addition to defects in workmanship or material. These retirement forces for rooftop PV may include (but are not limited to): weather (wind, electrical, and rain storms), fire, theft, vandalism, terminating lease contracts, roof failure, and obsolescence. Considering all forces of asset retirement the average depreciable life of the PV modules could average 15-20 years (i.e., some may retire earlier or later). At this time, SCE proposes using an average service life of 20 years.

The estimated decommissioning cost for the solar PV system is approximately $75,000/MW in 2008 dollars. The decommissioning costs are expected to be incurred 20 years after the date of installation of the PV Production assets. So, SCE projected the costs at the expected retirement date. Depreciation accrual for decommissioning begins upon installation of the underlying assets. Table V-10 shows the future decommissioning estimates and the estimated future annual deprecation expense for the assets installed in each respective year.

Table V-12
Summary of Future Decommissioning Expenses (included in Depr. Expense)
thousands of dollars

Year Installed	MW	Year Retired	Decommissioning $75 / MW	Escalation Factor 1/	Decommissioning (retirement year$)	Annual Depreciation 2/
2008	5	2028	$375	1.6395	$615	$31
2009	50	2029	$3,750	1.6323	$6,121	$306
2010	50	2030	$3,750	1.6263	$6,099	$305
2011	50	2031	$3,750	1.6208	$6,078	$304
2012	50	2032	$3,750	1.6198	$6,074	$304
2013	45	2033	$3,375	1.6220	$5,474	$274

1 / Escalation factor is based on Global Insight Chain-Weighted GDP between year installed and year retired

2/ Assets are estimated to be installed mid-year, so the first year of estimated depreciation will be half the annual amount.

(ii) PV Rack

The PV rack is the support structure for the PV modules, made primarily of aluminum and miscellaneous hardware. Chapter III, Program Description, Section C, Description of Facilities explains the rack in detail. As a support structure, the estimated depreciable life of the PV rack is 30 years.

b) General Plant

The general plant in the Solar PV Program is the data acquisition system (DAS). The DAS will include data collection, metering, communication, and weather sensoring equipment. This equipment is primarily modern, digital electronic computer and microprocessor-equipment and is similar to SCE's existing Supervisory Control and Data Acquisition (SCADA) equipment. SCE's current authorized depreciation lives for this type of SCADA equipment ranges from 7 to 15 years.[35] For purposes of estimating depreciation in this filing, SCE used 10 years. The net salvage requirement for this equipment is estimated at zero percent.

c) Distribution Plant

The distribution plant is the equipment required to connect the solar PV generation to the distribution grid. The plant may include overhead conductor, underground conduit and conductor, disconnect switches, distribution line transformers, services, and other distribution equipment. SCE determined the estimated depreciation for these assets using composite depreciation rates based on SCE's 2006 General Rate Case (GRC) Decision[36] authorized depreciation rates for year 2008 cost estimates, and its proposed 2009 GRC[37] depreciation rates for years 2009 through 2014. The current authorized depreciation rates are based on an average service life of 30 to 55 years and net salvage requirements ranging from 0 to -100 percent.

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[35] D. 06-05-016. SCE's proposed depreciation lives in its 2009 GRC (A. 07-11-011) are the same.

[36] D. 06-05-016

[37] A. 07-11-011

3. Rate of Return

As authorized in D.06-05-039, SCE calculated the rate of return on rate base using SCE's current authorized rate of return of 8.75%, plus 1%, since this new plant will be utility-owned renewable generation.

4. O&M Expense

Table V-11 shows the estimated O&M expenses by year included in the estimated revenue requirements shown in Table V-10. Column C of Table V-13, shows the total estimated O&M expenses in the amount of $53.83 million in constant $2008 as supported in the previous chapters.[38] Column D includes the annual estimated incremental staffing expenses in the amount of $8.98 million as supported in Chapter IV.[39] Column E includes an estimate of the benefits associated with the incremental staffing in the amount of $3.63 million. Column F includes estimated escalation associated with the amounts included in Columns C through E based on escalation rates supported in SCE's 2009 GRC Application (A.07-11-011). Therefore, as shown in Column G, the total estimated nominal O&M expenses included in the estimated 2008 through 2014 annual revenue requirements is $74.79 million.

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[38] For example, the estimated maintenance and roof lease O&M for 2008 is calculated by multiplying 5 MW by $52,520/MW. For purposes of calculating and annual revenue requirement for 2014, SCE has included a full year of estimated O&M expenses.

[39] Table IV-9

Table V-13
Summary of Solar PV Program Calendar Year Estimated O&M Expenditures
$millions

Col. A	Col. B	Col. C	Col. D	Col. E	Col. F	Col. G
		Non-Labor	**Labor Related**			
Year	**Cumulative Installed MW**	**$2008 Constant**	**Labor $2008 Constant**	**Benefits $2008 Constant**	**Escalation**	**Total Nominal**
2008	5	0.26	0.74	0.30	-	1.30
2009	55	2.89	1.29	0.52	0.13	4.83
2010	105	5.51	1.39	0.56	0.44	7.91
2011	155	8.14	1.39	0.56	0.92	11.01
2012	205	10.77	1.39	0.56	1.58	14.29
2013	250	13.13	1.39	0.56	2.38	17.46
2014	250	13.13	1.39	0.56	2.90	17.99
Total		53.83	8.98	3.63	8.35	74.79

5. Income Taxes

SCE estimates income taxes by following the rules and methods traditionally adopted in the Company's GRC. Specifically, in computing tax depreciation, SCE uses the five year MACRS (Modified Accelerated Cost Recovery System) tax life for federal purposes and a five year life, straight-line method, for computing state tax depreciation. For Federal tax purposes, SCE includes 50% Bonus Depreciation for all 2008 capital additions that meet prescribed requirements. Deferred taxes are estimated as required by the Internal Revenue Code. SCE computes tax basis by removing any recorded Allowance for Funds Used During Construction (AFUDC) and replacing it with tax capitalized interest following the rules of Internal Revenue Code Section 263A. SCE also computes a tax deduction for the benefits of Internal Revenue Code Section 199. SCE computes tax expense and the corresponding

deferred taxes using the applicable Federal corporate tax rate of 35% for each year and an apportioned state corporate tax rate, as applicable.[40]

C. Description of Solar PV Program Balancing Account (SPVPBA)

SCE requests that the Commission authorize SCE to establish the SPVPBA to record the difference between: 1) the actual incremental O&M and capital-related revenue requirement associated with the Solar PV Program and; 2) the recorded Solar PV Program-related generation retail revenue. The SPVPBA will ensure that no more and no less than the reasonably incurred actual revenue requirement associated with the Solar PV Program is ultimately recovered from customers. The incremental O&M costs that will be recorded in the SPVPBA will include such things as the cost of cleaning, inspecting and monitoring the solar PV equipment, lease costs, insurance, incremental labor associated with the staffing requirements to manage the project, and travel expenses.[41] SCE proposes to also record the revenue requirement (i.e. depreciation,[42] property, payroll and income taxes, and return calculated at the authorized rate of return on rate base) associated with actual Solar PV Program capital additions.[43] Consistent with D.06-05-039, SCE will calculate the rate of return on rate base using SCE's current authorized rate of return of 8.75%, plus 1%, since this new plant will be utility-owned renewable generation.[44]

SCE will continue to record entries in the SPVPBA until both the O&M and capital-related revenue requirements are included in SCE's GRC revenue requirement, which is expected to be January 1, 2015, or sooner.

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[40] Congress is currently proposing legislation that could produce tax credits for solar projects. If enacted and if this project meets the requirements and qualifications of any enacted legislation, SCE will record any solar tax credit benefits in the SPVPBA taking into account the normalization requirements

[41] SCE will also record applicable benefits associated with any incremental labor that is recorded in the SPVPBA.

[42] The depreciation expense recorded to the SPVPBA for these assets will reflect the current authorized depreciation rates for the respective general plant accounts and will be updated, as necessary, as a result of SCE's 2009 GRC decision and any subsequent General Rate Case decision regarding depreciation of the respective plant accounts.

[43] Capital additions include overheads such as AFUDC, capitalized property and payroll taxes, and pension and benefits added to direct expenditures of $875 million.

[44] The Commission in D.06-05-039 implemented the California Legislature's authorization for increased incentive for utility ownership of renewable generation.

On March 27, 2008, SCE filed an advice letter requesting Commission authority to establish the SPVPMA to record all incremental O&M expenses, invoiced costs for outside services (e.g., consultants and vendors), insurance, and any capital-related revenue requirement incurred as a result of SCE's Solar PV Program activities prior to Commission approval of SCE's ratemaking request in this instant application. The establishment of the SPVPMA is necessary to ensure that the Solar PV Program can proceed without delay and without precluding cost recovery at a future date. Similar to all Commission-approved memorandum accounts, the SPVPMA will protect against retroactive ratemaking concerns, but will not guarantee recovery in rates of any recorded costs prior to Commission review and approval. SCE plans to only use the interim ratemaking (i.e. the SPVPMA) while this application is pending in 2008 to record incremental O&M and capital-related revenue requirement associated with the first $25 million of direct capital expenditures. If the Commission does not act on this application in 2008, SCE will record incremental O&M and capital-related revenue requirement above $25 million in the SPVPMA until a final Commission decision is issued. Finally, upon approval of this application, SCE will transfer the balance recorded in the SPVPMA to the SPVPBA.

At the end of each year, SCE proposes to transfer the balance recorded in the SPVPBA, either over- or under-collected, to the generation sub-account of the Base Revenue Requirement Balancing Account (BRRBA). At the beginning of each year, SCE consolidates the December 31st balance recorded in the generation sub-account of the BRRBA in generation rate levels to be recovered from bundled service customers.

D. Proposed Reasonableness Review and Standard for Reasonableness Review

SCE proposes to include in its annual April ERRA Reasonableness proceedings, testimony supporting the reasonableness of the O&M costs recorded in the SPVPBA during the prior calendar year. SCE proposes that if SCE's direct capital expenditures in each calendar year of the program are less, on a $/W basis than the amount in Table V-14 below, then those capital expenditures will be deemed to be reasonable.

Table V-14
Reasonableness Review Threshold For Direct Solar PV Program Capital Costs (2008$)[45]

Expenditures Incurred During	$/W
2008	5.50
2009	3.83
2010	3.83
2011	3.83
2012	3.83
2013	3.76

The threshold levels contained in Table V-14 are reasonable because they represent SCE's base case estimate of Solar PV Program cost per Watt, as shown on Table IV-6, plus a reasonable 10% contingency.

1. Inflation Adjustment

Because direct capital expenditures will be recorded in nominal dollars during each year of the project, the $/W costs in Table V-14 will have to be adjusted for general price inflation between 2008 and later years. SCE proposes to accomplish this by multiplying the $/W costs in 2008 dollars by the ratio of the Gross Domestic Product Price Index (GDPPI) for the calendar year being reviewed to the Gross Domestic Product Price Index for 2008. Expressed as a formula where *RT* is the reasonableness threshold:

$$RT_t = RT_{\text{Table V-14}} \times \frac{GDPPI_t}{GDPPI_{2008}}$$

2. Reasonableness Review Procedure

In any year that SCE's direct capital expenditures, on a $/W basis, exceed the amounts set forth in Table V-14 above, as escalated, SCE will include, in its annual April ERRA Reasonableness

[45] These threshold amounts will be escalated to nominal year amounts for use in reasonableness review.

proceedings, testimony supporting the reasonableness of the capital expenditures during the previous calendar year. Even if no reasonableness testimony is required, SCE will include for Commission audit and review the O&M and capital revenue requirement recorded in the SPVPBA in its annual April ERRA Reasonableness proceeding.

Appendix A

Witness Qualifications

SOUTHERN CALIFORNIA EDISON COMPANY

QUALIFICATIONS AND PREPARED TESTIMONY

OF RICHARD FISHER

Q. Please state your name and business address for the record.

A. My name is Richard Fisher, and my business address is 2244 Walnut Grove Avenue, Rosemead, California 91770.

Q. Briefly describe your present responsibilities at the Southern California Edison Company.

A. I am the manager of the Rate Base and Depreciation group in the Capital Recovery Division, responsible for recorded depreciation, nuclear decommissioning, and portions of rate base.

Q. Briefly describe your educational and professional background.

A. I have a Bachelor of Science Degree in Business Administration, with an emphasis in Finance, Real Estate, and Law, from California State Polytechnic University, Pomona. I am currently completing course work towards a Masters degree in Business Administration at the University of Southern California and will be completed by June 2008. I am a member of the Society of Depreciation Professionals and have been qualified as a Certified Depreciation Professional.

Since my employment with Southern California Edison in 1999 I have been with the Capital Recovery Division of the Controllers Department. My responsibilities have included functions involving depreciation and nuclear decommissioning accounting, depreciation studies, and the development of forecasting models for plant additions, rate base, and depreciation expense in direct support of the Company's regulatory proceedings. I have previously testified before the California Public Utilities Commission.

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony in this proceeding is to sponsor those portions of Exhibit No. SCE-1, entitled *Solar Photovoltaic (PV) Program Testimony,* as identified in the Table of Contents thereto.

Q. Was this material prepared by you or under your supervision?

A. Yes, it was.

1 Q. Insofar as this material is factual in nature, do you believe it to be correct?

2 A. Yes, I do.

3 Q. Insofar as this material is in the nature of opinion or judgment, does it represent your best

4 judgment?

5 A. Yes, it does.

6 Q. Does this conclude your qualifications and prepared testimony?

7 A. Yes, it does.

SOUTHERN CALIFORNIA EDISON COMPANY
QUALIFICATIONS AND PREPARED TESTIMONY
OF PAUL T. HUNT, JR.

Q. Please state your name and business address for the record.

A. My name is Paul T. Hunt, Jr., and my business address is 2244 Walnut Grove Avenue, Rosemead, California 91770.

Q. Briefly describe your present responsibilities at the Southern California Edison Company.

A. I am the Manager of Regulatory Finance and Economics, supervising the Regulatory Finance Division of the Treasurer's Department. My present responsibility is to apply economic, financial, and statistical analysis to regulatory issues and for internal corporate purposes.

Q. Briefly describe your educational and professional background.

A. I received a Bachelor of Arts degree in Economics from Pomona College in 1975, a Master of Arts degree in Economics from Stanford University in 1976, and a Doctor of Philosophy degree from Stanford University in 1981. I joined the Southern California Edison Company as an Associate Economist in the Treasurer's Department in July 1980. I was promoted to Economist in 1982 and Senior Economist in 1984. In 1989, I transferred to the Regulatory Policy and Affairs Department as a Regulatory Economics Consultant. I returned to the Treasurer's Department in 1996 as a Senior Economist. In 1997, I was promoted to Project Manager. I was promoted to my present position in 2000.

I have testified before the California Public Utilities Commission and the Federal Energy Regulatory Commission.

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony in this proceeding is to sponsor the portions of Exhibit No. SCE-1, entitled *Solar Photovoltaic (PV) Program Testimony,* as identified in the Table of Contents thereto.

1 Q. Was this material prepared by you or under your supervision?

2 A. Yes, it was.

3 Q. Insofar as this material is factual in nature, do you believe it to be correct?

4 A. Yes, I do.

5 Q. Insofar as this material is in the nature of opinion or judgment, does it represent your best
6 judgment?

7 A. Yes, it does.

8 Q. Does this conclude your qualifications and prepared testimony?

9 A. Yes, it does.

SOUTHERN CALIFORNIA EDISON COMPANY
QUALIFICATIONS AND PREPARED TESTIMONY
OF DEBORAH J. KLUN

Q. Please state your name and business address for the record.

A. My name is Deborah J. Klun, and my business address is 2244 Walnut Grove Avenue, Rosemead, California 91770.

Q. Briefly describe your present responsibilities at the Southern California Edison Company.

A. I am a Director in the Tax Department. Since late April 2007, I have been responsible for all tax matters in CPUC and FERC rate filings made by the company.

Q. Briefly describe your educational and professional background.

A. I hold an undergraduate degree in Accounting from De Paul University, a Master's degree in Taxation from De Paul University and a Juris Doctorate degree from Northwestern University. I have passed the CPA exam (Illinois), and am licensed to practice law in Hawaii. I have been employed in the Edison Tax Department since 1988. I have held various positions in the tax department, having responsibility for Tax Research and Planning, IRS Audits and the Accounting for Income Tax function, as well as, tax rate regulation. Prior to joining Edison, I worked as Director of Federal Tax for another corporation, I practiced with a large law firm and worked for a big four CPA firm.

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony in this proceeding is to sponsor those portions of Exhibit No. SCE-1, entitled *Solar Photovoltaic (PV) Program Testimony,* as identified in the Table of Contents thereto.

Q. Was this material prepared by you or under your supervision?

A. Yes, it was.

Q. Insofar as this material is factual in nature, do you believe it to be correct?

A. Yes, I do.

Q. Insofar as this material is in the nature of opinion or judgment, does it represent your best judgment?

A. Yes, it does.

1 Q. Does this conclude your qualifications and prepared testimony?

2 A. Yes, it does.

SOUTHERN CALIFORNIA EDISON COMPANY
QUALIFICATIONS AND PREPARED TESTIMONY
OF MARK E. NELSON

Q. Please state your name and business address for the record.

A. My name is Mark E. Nelson, and my business address is 8631 Rush Street, Rosemead, California 91770.

Q. Briefly describe your present responsibilities at the Southern California Edison Company.

A. I am the Director of Generation Planning and Strategy in the Generation Business Unit. My present responsibility includes the broad support of generation initiatives and regulatory efforts at SCE, and management of the Project Development Division.

Q. Briefly describe your educational and professional background.

A. I earned a Bachelor of Science degree in Economics from Iowa State University with emphasis work in Chemical Engineering and Systems. I earned a Master of Science degree in Econometrics from Iowa State University with thesis work in electricity demand analysis. I first joined the Southern California Edison Company as a Planning Engineer in 1991 and held various management positions through 1996, including Manager of Real Time Pricing and Customer Software Systems. In 1996 I joined Edison Source and held a number of management positions including Director of Retail Energy Operations until my departure in 1999 following the cessation of energy marketing activities. From 1999-2003, I served as Managing Consultant of Commerce Venture Group LLC, with primary responsibility for energy sector consulting and analysis. I rejoined Southern California Edison in 2003 as Integrated Planning Manager and was subsequently promoted to Manager of Strategic Projects in the Resource Planning & Strategy Department prior to promotion to my current position.

Prior to joining Southern California Edison, I served as a Consultant for Midwest Solar, Inc., a leading national supplier of large scale solar thermal systems, with responsibility for economic and engineering analysis from 1980-83. From 1983-88, I held management and analysis positions with subsidiaries of MidAmerican Energy, with responsibility for generation and

transmission projects, economic analysis, regulatory affairs and customer services. From 1988-91, I served as Vice President of Analysis for DATASSIST, where I was responsible for economic and statistical analysis of electric and gas utility projects.

I am the author of a number of energy and business books and articles, including: An Econometric Study of Residential Electricity Demand (ISBN 1-56471-005-X), Fundamentals of Business Process Analysis (1-56471-009-2), and "Understanding Natural Gas Demand for Electric Utilities."

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony in this proceeding is to sponsor the portions of Exhibit No. SCE-1 entitled *Solar Photovoltaic (PV) Program Testimony*, as identified in the Table of Contents thereto.

Q. Was this material prepared by you or under your supervision?

A. Yes, it was.

Q. Insofar as this material is factual in nature, do you believe it to be correct?

A. Yes, I do.

Q. Insofar as this material is in the nature of opinion or judgment, does it represent your best judgment?

A. Yes, it does.

Q. Does this conclude your qualifications and prepared testimony?

A. Yes, it does.

SOUTHERN CALIFORNIA EDISON COMPANY
QUALIFICATIONS AND PREPARED TESTIMONY
OF RUDY PEREZ

Q.1 Please state your name and business address for the record.

A.1 My name is Rodolfo "Rudy" Perez and my business address is Southern California Edison Company, 8631 Rush Street, Rosemead, California 91770.

Q.2 Briefly describe your present responsibilities at the Southern California Edison Company.

A.2 I am the current Project Manager for the development of the Solar Photovoltaic Program (SPVP) within the Generation Business Unit Planning and Strategy Group at the Southern California Edison Company.

Q.3 Briefly describe your educational and professional background.

A.3 I hold bachelor degrees in Chemical Engineering and Economics from the University of Notre Dame (Indiana) as well as a Masters in Business Administration from California State University – Long Beach. I also hold a California Professional Engineer's License in Mechanical Engineering. I have been an SCE employee for over 25 years holding various engineering and management positions within Generation, Transmission & Distribution and the Renewable and Alternative Power Organizations.

Q.4 What is the purpose of your testimony in this proceeding?

A.4 The purpose of my testimony in this proceeding is to sponsor the portions of Exhibit No. SCE-1, entitled *Solar Photovoltaic (PV) Program Testimony,* as set forth in the Table of Contents thereto.

Q.5 Was this material prepared by you or under your supervision?

A.5 Yes, it was.

Q.6 Insofar as this material is factual in nature, do you believe it to be correct?

A.6 Yes, I do.

Q.7 Insofar as this material is in the nature of opinion or judgment, does it represent your best judgment?

A.7 Yes, it does.

Q.8 Does this conclude your qualifications and prepared testimony?

A.8 Yes, it does.

SOUTHERN CALIFORNIA EDISON COMPANY

QUALIFICATIONS AND PREPARED TESTIMONY

OF GENE E. RODRIGUES

Q. Please state your name and business address for the record.

A. My name is **Gene E. Rodrigues**, and my business address is 6042A N. Irwindale Avenue, Irwindale, CA 91702.

Q. Briefly describe your present responsibilities at the Southern California Edison Company (SCE).

A. I am presently the Director of Energy Efficiency for SCE. In that capacity, I have direct oversight of SCE's portfolio of energy efficiency programs, low income energy efficiency programs, the California Alternate Rates for Energy (CARE) program, the self generation incentives program, California Solar Initiative and the measurement & evaluation and regulatory support functions for these areas.

Q. Briefly describe your educational and professional background.

A. I received a Bachelor of Science degree in Education from Northern Arizona University in 1980 and a Juris Doctor degree from the University of California, Hastings College of Law in 1988. Before coming to SCE, I taught high school in Arizona and practiced law with a civil litigation firm in Los Angeles. In 1990, I joined SCE's regulatory law department, where I provided legal support for SCE's energy efficiency programs, among other things. Since moving to the business side of SCE, I have held various positions within the Customer Service Business Unit, managing energy efficiency policy, operations and regulatory functions. My current position is Director of Energy Efficiency. I have previously practiced law and testified before the Commission.

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony in this proceeding is to sponsor the portions of Exhibit No. SCE-1, entitled *Solar Photovoltaic (PV) Program Testimony,* as set forth in the Table of Contents thereto.

Q. Was this material prepared by you or under your supervision?

1 A. Yes, it was.
2 Q. Insofar as this material is factual in nature, do you believe it to be correct?

3 A. Yes, I do.
4 Q. Insofar as this material is in the nature of opinion or judgment, does it represent your best
5 judgment?

6 A. Yes, it does.
7 Q. Does this conclude your qualifications and prepared testimony?

8 A. Yes, it does.

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SOUTHERN CALIFORNIA EDISON COMPANY
QUALIFICATIONS AND PREPARED TESTIMONY
OF DOUGLAS A. SNOW

Q. Please state your name and business address for the record.

A. My name is Douglas A. Snow, and my business address is 2244 Walnut Grove Avenue, Rosemead, California 91770.

Q. Briefly describe your present responsibilities at the Southern California Edison Company (SCE).

A. I am the Manager of Revenue Requirements in SCE's Regulatory Policy and Affairs (RP&A) Department. As such, I am responsible for overseeing the operation of various Balancing and Memorandum Accounts and the associated disposition of the balances in those accounts for ratemaking purposes.

Q. Briefly describe your educational and professional background.

A. I graduated from Texas A&M University in May of 1982 with a Bachelors of Science Degree in Industrial Engineering. In June of 1982, I went to work for Southwestern Public Service Company (SPS) in west Texas. While there, I attained a title of Supervisory Engineer and was responsible for revenue requirement calculations and rate design for both retail and resale customers. I filed testimony on behalf of SPS before the Texas Public Utility Commission and the Federal Energy Regulatory Commission. In November of 1993, I went to work for the Southern California Edison Company as a Financial Analyst in the FERC Pricing section in the RP&A Department. While working in the FERC section, I was responsible for the rate design for SCE's requirements sales for resale, Wheeling Access Charges, and wholesale Distribution Access Charges. In March 1998, I became a Supervisor in the Revenue Requirements division of RP&A, responsible for supervising a group of analysts that oversee the forecasting and recording entries associated with all CPUC regulatory mechanisms. In December 2001, I was promoted to the position of manager in the Revenue Requirements division of RP&A. In August 2006, I was promoted to my current position as Manager of Revenue Requirements. I have previously testified before the California Public Utilities Commission.

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony in this proceeding is to sponsor portions of Exhibit No. SCE-1, entitled *Solar Photovoltaic (PV) Program Testimony,* as identified in the Table of Contents thereto.

Q. Was this material prepared by you or under your supervision?

A. Yes, it was.

Q. Insofar as this material is factual in nature, do you believe it to be correct?

A. Yes, I do.

Q. Insofar as this material is in the nature of opinion or judgment, does it represent your best judgment?

A. Yes, it does.

Q. Does this conclude your qualifications and prepared testimony?

A. Yes, it does.

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BEFORE THE
PUBLIC UTILITIES COMMISSION
OF THE
STATE OF CALIFORNIA

Order Instituting Rulemaking to Develop	)	
Additional Methods to Implement the California	)	Rulemaking: 06-02-012
Renewables Portfolio Standard Program	)	(Filed February 16, 2006)
	)	

Pre-Workshop Comments of GreenVolts, Cleantech America, and Community Environmental Council on the 2008 Market Price Referent

Bill Barnes
Chief Executive Officer
Cleantech America, Inc.
50 California Street, Suite 1500
San Francisco CA 94111
Telephone: 415-277-5455
Email: b.barnes@cleantechamerica.com

Craig Lewis
Vice President of Government Relations
GreenVolts
50 First Street, Suite 507
San Francisco, CA 94105
Telephone: 650-796-2353
E-mail: craig.lewis@greenvolts.com

Tamlyn Hunt
Energy Program Director / Attorney
Community Environmental Council
26 W. Anapamu, 2nd Floor
Santa Barbara, CA 93101
Telephone: 805-963-0583 x122
Email: thunt@cecmail.org

6 March 2008

Locational Benefits of WDG

BEFORE THE
PUBLIC UTILITIES COMMISSION
OF THE
STATE OF CALIFORNIA

Order Instituting Rulemaking to Develop	)	
Additional Methods to Implement the California	)	Rulemaking: 06-02-012
Renewables Portfolio Standard Program	)	(Filed February 16, 2006)
	)	

Pre-Workshop Comments of GreenVolts, Cleantech America, and Community Environmental Council on the 2008 Market Price Referent

Pursuant to Administrative Law Judge Anne Simon's Ruling dated February 8, 2008 (ALJ Ruling), GreenVolts, Cleantech America, and Community Environmental Council (collectively the "Joint Parties") present opening comments on issues associated with the 2008 market price referent (2008 MPR). The Joint Parties' comments focus on Section 4.1.4 of the ALJ Ruling, which asks parties to discuss how locational pricing should be incorporated into the 2008 MPR. The Joint Parties' primary interest in this proceeding is ensuring that the locational benefits of intelligently-sited renewable energy generation are reflected fully in the 2008 MPR. Although locational pricing is the focus of these comments, the Joint Parties also have a strong interest in the other issues outlined in the ALJ Ruling, and support the comments on those matters that are being filed concurrently by the California Wind Energy Association (CalWEA), the California Cogeneration Council (CCC), and the Concentrated Solar Power companies (CSP).

GreenVolts is a San Francisco company with the mission of making solar energy economical. The company has developed state-of-the-art concentrating photovoltaic (CPV) technology that achieves unparalleled solar-to-electricity conversion efficiency through an innovative integration of optics and solar tracking. Like central station power plants, GreenVolts' technology is a complete power plant designed for delivering the lowest levelized

cost of energy. Also, like traditional solar panels on roof-tops, GreenVolts' power plants are sited close to loads, increasing efficiency and further reducing cost. GreenVolts is currently constructing a California Public Utilities Commission (CPUC) approved (Resolution E-4132) solar power plant that will fulfill a 20-year power purchase agreement (PPA) with Pacific Gas & Electric (PG&E). This 2 MW power plant will be interconnected to PG&E's 12kV distribution lines near Tracy, California. In addition to having a high Generator Meter Multiplier (GMM), reflecting that generation at this delivery point already reduces system average line losses, the site is within two miles of a major new housing development that will become one of the largest loads in the region. GreenVolts expects to widely replicate such utility-scale wholesale distributed generation (WDG) solar power plants, which will deliver to California's ratepayers not only significant amounts of clean solar energy, but also the tangible and quantifiable locational benefits that are the subject of these comments.

Cleantech America, Inc. is a leading California-based developer of in-grid, emission-free, photovoltaic (PV) solar farms and other renewable energy projects sized 5 MW and greater. The company recently received approval from the CPUC for a 5 MW solar PV PPA with PG&E, the largest such contract with an IOU approved to date under the state's RPS program. Cleantech's business plan is, in part, to site projects near utility distribution or transmission systems close to serviced load. The company's in-grid strategy is intended to provide ratepayers with significant locational benefits, including improved air quality, avoided congestion costs, reduced need for major new bulk transmission, and regional green collar jobs growth. Coupled with the company's strategy to reduce the cost of PV and other solar electricity generation through economies of scale, locational pricing offers ratepayer benefits that are not currently reflected in the MPR.

The Community Environmental Council is a member-supported environmental non-profit organization formed in Santa Barbara in 1970 and is the leading environmental organization in the mid-California area. In 2004, the organization shifted its primary focus to energy and transportation issues and began spearheading a regional effort to wean communities from fossil

fuels over the next two decades. The California Environmental Council combines community efforts on a number of energy and climate change-related issues with action on associated state and federal policy issues. The state and federal policy action is directly informed by the organization's extensive experience at the local level.

I. SUMMARY

The Joint Parties believe there is an underserved renewable energy market segment where renewable generation supplying wholesale power can be sited on utility distribution systems near significant loads. The renewable, wholesale distributed generation (WDG)[1] supplied by new technology like GreenVolts' promises to provide ratepayers with significant locational benefits, compared to large renewable projects that typically must be sited in remote locations where large tracts of land are available. The locational benefits of WDG include:

- avoiding the need for major new bulk transmission facilities,
- meeting local resource adequacy needs,
- reducing transmission line losses,
- avoiding congestion costs,
- reducing distribution line losses,
- avoiding demand-related distribution investments.

These benefits are not currently reflected in the MPR, which serves as the key pricing benchmark for new renewable generation. The MPR has been designed, like the entire RPS program, with a focus on large renewable projects that supply tens or hundreds of megawatts of wholesale power delivered into the bulk transmission system. However, state policy is beginning to recognize the potential of renewable WDG, through initiatives such as the AB 1969 "feed-in" tariffs whose price is set at the prevailing MPR. If California is to realize the full

[1] "Wholesale distributed generation" (WDG) projects are significantly distinguished from traditional "distributed generation" (DG), which generally refers to small, retail generation projects sized to serve a specific on-site load, with power flowing onto the utility distribution system only to the limited extent that on-site generation happens to exceed on-site load.

potential of renewable WDG, the MPR applicable to small renewable projects sited on the distribution system should reflect the enhanced benefits that ratepayers derive from the favorable location of this new renewable generation.

These comments respond to the ALJ's Ruling asking whether the 2008 MPR should incorporate locational pricing, and explain how the 2008 MPR should be modified to include the locational benefits of WDG projects. The Locational Marginal Pricing (LMP) under the CAISO's new Market Re-design and Technology Update (MRTU) program will provide data on transmission line loss and congestion benefits at thousands of locations on the CAISO grid. WDG projects can avoid the distribution line losses specified in the utilities' Wholesale Distribution Access Tariffs (WDATs).

Finally, the Commission's adopted E3 model for the avoided costs associated with energy efficiency programs includes a time-dependent, hourly valuation of avoided investment-related Transmission & Distribution (T&D) costs. This model can be used to value the avoided T&D costs from a WDG project; these costs should be added to the MPR applicable to the project. The Joint Parties are aware that the utilities have been reluctant to recognize that generators avoid T&D costs unless located in an area where specific costs can be avoided. In pursuit of benefits for all parties including ratepayers, the Joint Parties stand ready to work cooperatively with the utilities to identify those areas of their systems where the T&D benefits of WDG are at least as large as those specified in the E3 model, and to site renewable WDG projects in those areas. To encourage the development of renewable WDG generation, the Joint Parties recommend that the Commission direct the utilities to publish, by 31 December 2008, a list of the distribution substations on their systems where WDG would avoid T&D costs at least as high as those specified in the E3 model – in essence, a distribution-level version of the Transmission Ranking Cost Report that the utilities publish to indicate the availability and cost of bulk transmission on their systems.

II. JOINT PARTIES' INTEREST IN THIS PROCEEDING

The Joint Parties have studied the tangible and quantifiable locational benefits of wholesale distributed generation (WDG) – the market segment where utility-scale, wholesale energy is generated on the distribution network close to loads. The ability to locate renewable generation, and solar power plants in particular since those satisfy peak demand with ultra-clean energy, on the distribution network close to loads promotes local resource adequacy and avoids the challenges associated with expanding the state's transmission infrastructure. These challenges include costly transmission investment requirements; notoriously long planning, permitting and build-out times; the significant environmental impacts of new transmission lines; congestion bottlenecks; and the substantial line losses associated with the long-distance transmission of electricity. WDG also can reduce losses on the distribution system, avoid investments to expand the distribution system, and improve reliability by generating power close to where it is consumed.

Given that the MPR is the statutory benchmark for a reasonable, long-term market price for electricity from new renewable generation,[3] the MPR should recognize the enhanced benefits to ratepayers from the intelligent siting of new renewable generation at locations that offer the greatest benefit to ratepayers. Hence, the locational benefits of WDG should be incorporated into the MPR.

III. STATE POLICY IS JUST BEGINNING TO ADDRESS RENEWABLE WHOLESALE DISTRIBUTED GENERATION.

Despite the advantages of renewable WDG, this is a market that, until very recently, has been largely ignored by California's otherwise laudable efforts to promote development of renewable technologies for electric generation. For example, the incentives available under the California Solar Initiative (CSI) are limited to distributed generation (DG) facilities serving

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[2] P.U. Code Section 399.15(c).

retail, on-site loads and to projects producing no more than 1 MW. The RPS program is structured to award power purchase contracts to very large renewable generation projects delivering wholesale power into the state's transmission grid. Large RPS projects require significant land area in regions with abundant renewable resources, the combination of which are available predominantly in locations remote from the state's load centers. As a result, the availability of adequate bulk transmission is a major challenge for large RPS projects. Further, the successful participation in the full RPS solicitation process is a complex and expensive endeavor, which presents a significant barrier to small renewable WDG projects. GreenVolts and Cleantech America both have direct experience with the full cycle of the RPS request for offer (RFO) process, and both have found that the high cost and effort associated with participating in the solicitation process significantly diminishes the economic attractiveness of the RPS for small projects, certainly including projects with a capacity of 5 MW or less.

California is beginning to take initial steps to address the needs of renewable WDG. On February 14, 2008, the Commission issued Resolution E-4137, which gave final approval to what the Commission described as "feed-in" tariffs under which small renewable generators (with up to 1.5 MW in capacity delivered to the utility) can sell wholesale power to the state's investor-owned utilities under simplified 10-, 15-, or 20-year contracts. The price under these tariffs will be the prevailing MPR price. These feed-in tariffs were mandated in AB 1969, which the Commission subsequently implemented in Decision No. 07-07-027 and Resolution E-4137.[3]

The AB 1969 tariffs will be available for up to 480 MW of new renewable generation. 250 MW of this capacity will be available only to projects owned and operated by public water and wastewater agencies, but pursuant to D. 07-07-027 PG&E and Edison will make 230 MW of capacity available to small renewable projects at any site, with a size limit per project of up to 1.5 MW delivered to the utility.[4] The Commission noted that "these 'feed-in tariffs' present a

[3] AB 1969 added P.U. Code Section 399.20.

[4] A project selling power to a utility under these tariffs can be larger than 1.5 MW, so long as the project serves an on-site load such that the utility purchases no more than 1.5 MW of the project's excess generation.

simple mechanism for small renewable generators to sell power to a utility at predefined terms and conditions, without contract negotiations." CPUC President Michael Peevey observed that the AB 1969 feed-in tariffs would allow small generators to participate in the RPS program, because "up until now, only large renewable generators were able to effectively participate in the RPS program."[5] The availability of AB 1969 contracts at the prevailing MPR price increases the importance of ensuring that the locational benefits of WDG are incorporated accurately into the 2008 MPR. As explained in more detail below, such WDG projects provide ratepayers with significant and quantifiable benefits associated with intelligent siting close to loads, and the value of these significant locational benefits is not yet reflected in the MPR price.

IV. LOCATIONAL VALUATION UNDER MRTU

Section 4.1.4 of the ALJ Ruling requests comments on how locational pricing should be incorporated into the 2008 MPR, particularly once locational marginal pricing is implemented under the CAISO's MRTU program. GreenVolts appreciates the Commission's recognition of the importance of locational pricing; it is of particular importance to WDG, such as the WDG solar power plants that GreenVolts is developing.

Renewable WDG is generally interconnected to a utility's distribution system and produces more power than is needed by any on-site load. The excess power exported to the grid typically is consumed by nearby loads served from the same distribution system to which the generator is connected. The locational value of such generation is not captured in the current MPR, which is designed as a benchmark for large, transmission-level RPS projects comparable in size to the 500 MW combined-cycle gas turbine (CCGT) facility on which the MPR is based. The MPR is a statewide value designed to capture a "representative statewide" estimate for the

[5] See the CPUC's February 14, 2008 press release, "CPUC Approves Feed-In Tariffs...," available at http://docs.cpuc.ca.gov/WORD_PDF/NEWS_RELEASE/78824.PDF.

costs of a new CCGT plant built in California.[6] The MPR calculation uses a 50/50 average of the delivered costs of natural gas in northern and southern California, and includes a line loss adjustment based on an average of line losses only on the California Independent System Operator's (CAISO) transmission grid. Thus, the current MPR represents the statewide average cost of large amounts of wholesale electricity delivered to the load center at transmission voltages.

Renewable WDG such as GreenVolts' Tracy project will provide locational benefits to California ratepayers that are not now reflected in the MPR, including:

- lower transmisison line losses,
- lower intra-zonal congestion,
- reduced distribution line losses, and
- avoided transmission and distribution investments.

Each of these benefits is discussed in the sections below. MRTU will enable the more accurate pricing of the first two of these benefits, and the Commission has existing methodologies to value the other two, which are discussed in Section V.

A. Transmission Line Losses.

Today, GMMs are used for the locational valuation of line loss impacts on the CAISO transmission grid. GMMs measure the average transmission line losses to deliver power to a virtual load center. The MPR price is adjusted by the system average GMM,[7] and the Joint Parties understand that typical RPS contracts pay renewable generators for their generation adjusted by their site-specific GMM.

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[6] See D. 03-06-071, at 21.

[7] Currently, the system average GMM used in the MPR model is the simple average of the GMMs on the CAISO grid. The use of the simple average GMM appears to understate average transmission losses on the CAISO grid; the accurate representation of CAISO system line losses would be the average GMM weighted by the output of each generator. The Joint

The valuation of line losses will change under MRTU. The new LMP method will provide a line loss component of the market price at each node. This market-based loss component will reflect marginal losses at each node, a significant change from the GMM methodology, which uses losses scaled to system average losses. Under MRTU, the CAISO also will provide aggregated losses across all of the nodes on its system and across each utility's service territory. For example, assume a new renewable generator's node has an annual average loss component of $1.50 per MWh vs an annual system average loss component of $2.00 per MWh. The MPR applicable to that project should be increased by $0.50 per MWh to reflect the ratepayer benefit of the reduced losses associated with that project's favorable location. In this way, an MPR specific to each project could be determined, in order to reflect accurately a project's site-specific annual losses under MRTU compared to the system average losses.

B. Congestion

Today, intra-zonal congestion is not priced in the market or in the MPR. However, under MRTU, the explicit valuation of intra-zonal congestion at each node will be possible, as congestion, like line losses, also will be an explicit component of the LMP price at each node. It will be possible to calculate system average congestion costs and to include them in the statewide MPR. Most important, similar to line losses, the MPR applicable to a specific project could be adjusted to reflect a project's site-specific annual congestion costs under MRTU, compared to the system's annual average congestion costs measured either over the whole CAISO system or over the purchasing utility's service territory.

C. MRTU Timing

While MRTU is not expected to "go live" until the September 2008 time-frame, the Commission should work toward incorporating MRTU line loss and congestion constructs into the 2008 MPR. The Joint Parties urge the Commission to devote effort at the upcoming workshop to incorporate MRTU constructs into the 2008 MPR. Active participation by CAISO and Energy Division personnel familiar with LMP pricing should make this process effective.

Parties support the comments of CalWEA / CCC / CSP on this point.

V. AVOIDED TRANSMISSION AND DISTRIBUTION COSTS

Renewable WDG located on the distribution system, and serving local loads, can allow the IOUs to avoid both distribution losses and investment-related T&D costs. The impact of WDG will be to reduce demand on the distribution system, just as on-site DG and energy efficiency/demand-side management programs effectively reduce distribution system loads. As discussed below, the Commission has well-established tools to evaluate the benefits of such reductions.

A. Avoided Distribution Losses

The Commission has long recognized that QF generation located on the distribution system allows the utilities to avoid distribution system losses.[8] The Commission generally has looked to the utilities' Wholesale Distribution Access Tariffs (WDAT) as the source for avoided distribution losses. For example, in the Commission's most recent review of QF line losses – D. 01-01-007 – the Commission adopted Southern California Edison's and San Diego Gas & Electric's WDAT distribution loss factors as the measure of the distribution line losses avoided by QFs that deliver into the distribution systems of these utilities.[9] **Table 1** below summarizes the existing WDAT loss factors of the three major California IOUs, and recommends that they be used to assess the benefits of WDG in avoiding line losses on the distribution system. As losses increase significantly during periods of high demand, the Joint Parties submit that the use of these average loss factors will be conservative for renewable peaking projects. The MPR applicable to renewable WDG interconnected to the distribution system should be increased by one plus the distribution loss factors in Table 1, as given by the following formula:

WDG Distribution Loss Factor = 1 / (1 – WDAT Energy Loss Factor)

[8] D. 82-12-120, D.84-03-092, and D.87-12-066.
[9] D. 01-01-007, at 18 and Conclusion of Law 15.

Table 1: *Utility WDAT Energy Loss Factors*

Utility	Distribution Voltage	WDAT Energy Loss Factors
PG&E	Primary	1.25%
	Secondary	3.62%
SCE	Subtransmission	1.12%
	Primary	3.73%
SDG&E	All voltages	0%

Sources: PG&E WDAT tariff, D. 01-01-007 (SCE and SDG&E).

B. Avoided T&D Investments

The question of whether generation interconnected at the distribution-level, or energy efficiency programs that reduce end-use demand, allow the utilities to avoid T&D investments has been the subject of considerable debate. The Commission's adopted E3 model for the avoided costs associated with energy efficiency programs includes a time-dependent, hourly valuation of avoided investment-related T&D costs. The E3 model uses system-wide measures of avoided T&D costs – typically, marginal T&D costs calculated for use in electric rate design. When the Commission reviewed the E3 model in 2004 - 2005, the utilities opposed the inclusion of avoided T&D costs in the model, arguing that energy efficiency resources avoid T&D costs only in certain specific, case-by-case circumstances, such as on a rapidly-growing distribution circuit where an upgrade is needed in the near future.[10] The Commission rejected this position in D. 05-04-024, finding that "while a case-by-case analysis should be applied to determine payments related to specific projects for long-term conservation measures it is appropriate to credit programs with T&D avoided costs for program evaluation purposes."[11] The Joint Parties submit that the primary purpose of the MPR is to provide a benchmark for the RPS contract costs that ratepayers should bear; in effect, to determine what level of RPS program costs are fair and cost-effective for ratepayers to support. This function is similar to the use of the E3 model to

[10] *See* D. 05-04-024, at 35-36.

develop cost-effectiveness tests "for program evaluation purposes." From this perspective, it would be appropriate for the MPR to recognize generally that distribution-level generators can avoid investment-related T&D costs.

Additionally, the MPR is beginning to be used as a price for direct payments to certain renewable generators – for example, the MPR price is used directly in the AB 1969 feed-in tariffs. The Joint Parties expect that the utilities will oppose the use of the E3 model's avoided T&D costs as a component of the MPR used for such payments, unless the avoidance of such costs can be specifically documented "in the field." Hence, the Joint Parties propose to work cooperatively with the IOUs' T&D planners to identify sites that offer greater T&D benefits than the average avoided T&D values produced by the E3 model. GreenVolts and Cleantech welcome the opportunity to cooperate with the utilities to locate solar WDG at sites on the utility distribution systems where the solar peaking generation provides the greatest benefits for ratepayers, in terms of meeting load growth and peak period demands, and thus avoiding T&D investments. Projects sited in this cooperative way should receive an adder to their MPR value equal to the expected avoided T&D costs calculated by the adopted E3 model. The avoided T&D costs in the E3 model are average values for each IOU division or planning region. As a result, if renewable WDG is sited in locations with higher-than-average incremental T&D costs, ratepayers would be assured that they have received excess value if the MPR for such projects only includes average avoided T&D costs for that area, as calculated by the E3 model.

The E3 model's time-dependent valuation of avoided T&D costs includes avoided T&D costs for each hour of the year, and for each IOU division or planning region. Given the hourly output profile of a new renewable generator, the model can easily calculate an "avoided T&D adder" for that generator that could be added to the MPR applicable to the project. The general formula for such a WDG T&D adder is as follows:

$$\textbf{WDG T\&D Adder} = \Sigma_{\textbf{All hours}} \textbf{[E3 T\&D Costs x WDG Generation]} / \Sigma_{\textbf{All hours}} \textbf{WDG Generation}$$

[11] *Ibid.,*at 36.

Table 2 shows the results from using the E3 model to calculate such avoided T&D adders for each IOU division or planning region included in the E3 model, for both a baseload (7x24) output profile and for a representative solar photovoltaic (PV) output profile from a south-facing flat-plate PV system at a 38.5 degree tilt located in Sacramento, California. Table 2 also shows T&D breakouts. Note that the E3 model calculates that the solar generation profile produces about 75% of the avoided T&D benefits of the baseload profile; this is because PV output is high during the peak afternoon hours when peaks occur on the distribution system.

The Joint Parties note that actual experience with behind-the-meter solar DG developed under the Commission's Self Generation Incentive Program (SGIP) is beginning to validate the ability of distributed PV systems to reduce peak demands on utility distribution systems. The August 2007 evaluation report on the SGIP program shows that, in the summer of 2006, installed PV systems reduced distribution line loadings on peak summer afternoons by 42% to 56% of the PV systems' installed capacity.[12] The evaluation consultant, Itron, concluded that "SGIP technologies are seen to provide the potential for significant reduction in peak loading of the distribution system."[13] Itron noted a number of reasons why SGIP projects have not achieved an even greater level of capital-related savings on the distribution system:

> In addition to limited penetration of SGIP facilities within the distribution system, a number of other factors contribute to a lack of distribution capital savings. One of these is that the SGIP generators operate independently of the distribution system. Therefore, the SGIP owner does not know when the distribution peak is, nor do they have any incentive to operate during the peak even if they did know. In fact, the current SGIP rules prohibit an additional incentive to operate during the local capacity peak. Similarly, the distribution utility planners do not necessarily know which SGIP generators are being served by overloaded equipment, likely because the penetration of SGIP generators is not currently high enough to warrant close attention for capacity planning at the distribution level. In addition, SGIP owners choose where to install their systems, not the utility; therefore, there are not a concentrated number of installations in a single area of need that could provide significant load relief on a particular overloaded feeder or substation.[14]

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[12] GreenVolts' PV technology tracks the sun, and thus will sustain its output at higher levels than flat-plate PV over the course of a peak summer afternoon. As a result, GreenVolts' plants will achieve higher reductions in distribution line loadings, as a percent of project capacity, than the flat plate PV systems installed under SGIP.

[13] Itron, "CPUC Self-Generation Incentive Program – Sixth Year Impact Evaluation Report" (August 30, 2007), at Table 4-1 and pages 1-10 to 1-14.

[14] *Ibid.*, at 5-28.

E3 Model T&D Values (Levelized 20-year in 2008$)

		Transmission + Distribution				Transmission				Distribution			
Utility	Division	Baseload Profile		Solar Profile		Baseload Profile		Solar Profile		Baseload Profile		Solar Profile	
		$/kW-year	$/MWh	$/kW-year	$/MWh	$/kW-year	$/MWh	$/kW-year	$/MWh	$/kW-year	$/MWh	$/kW-year	$/MWh
PG&E	Central Coast	$46.07	$5.26	$35.70	$24.60	$1.55	$0.18	$1.20	$0.83	$44.51	$5.08	$34.50	$23.77
	De Anza	$58.67	$6.70	$46.95	$32.35	$1.55	$0.18	$1.24	$0.86	$57.11	$6.52	$45.71	$31.49
	Diablo	$55.62	$6.35	$44.51	$30.67	$1.55	$0.18	$1.24	$0.86	$54.06	$6.17	$43.27	$29.81
	East Bay	$11.57	$1.32	$8.97	$6.18	$1.55	$0.18	$1.20	$0.83	$10.02	$1.14	$7.77	$5.35
	Fresno	$48.24	$5.51	$37.08	$25.55	$1.55	$0.18	$1.19	$0.82	$46.68	$5.33	$35.89	$24.72
	Kern	$30.87	$3.52	$23.73	$16.35	$1.55	$0.18	$1.19	$0.82	$29.32	$3.35	$22.54	$15.53
	Los Padres	$46.82	$5.34	$37.47	$25.81	$1.55	$0.18	$1.24	$0.86	$45.26	$5.17	$36.23	$24.96
	Mission	$70.36	$8.03	$54.53	$37.57	$1.55	$0.18	$1.20	$0.83	$68.80	$7.85	$53.32	$36.74
	North Bay	$47.46	$5.42	$36.78	$25.34	$1.55	$0.18	$1.21	$0.83	$45.90	$5.24	$35.57	$24.51
	North Coast	$64.43	$7.35	$40.41	$27.84	$1.55	$0.18	$0.97	$0.67	$62.87	$7.18	$39.43	$27.17
	North Valley	$80.30	$9.17	$63.33	$43.63	$1.55	$0.18	$1.23	$0.84	$78.74	$8.99	$62.10	$42.78
	Peninsula	$20.90	$2.39	$16.19	$11.16	$1.55	$0.18	$1.20	$0.83	$19.34	$2.21	$14.99	$10.33
	Sacramento	$60.93	$6.96	$48.05	$33.11	$1.55	$0.18	$1.23	$0.84	$59.37	$6.78	$46.83	$32.26
	San Francisco	$16.89	$1.93	$13.09	$9.02	$1.55	$0.18	$1.20	$0.83	$15.34	$1.75	$11.89	$8.19
	San Jose	$44.65	$5.10	$35.74	$24.62	$1.55	$0.18	$1.24	$0.86	$43.10	$4.92	$34.49	$23.76
	Sierra	$66.84	$7.63	$52.71	$36.32	$1.55	$0.18	$1.23	$0.84	$65.29	$7.45	$51.49	$35.47
	Stockton	$69.90	$7.98	$55.94	$38.54	$1.55	$0.18	$1.24	$0.86	$68.34	$7.80	$54.69	$37.68
	Yosemite	$42.73	$4.88	$34.20	$23.56	$1.55	$0.18	$1.24	$0.86	$41.18	$4.70	$32.96	$22.70
SCE	Dominguez Hills	$45.91	$5.24	$32.93	$22.69	$26.09	$2.98	$18.71	$12.89	$19.82	$2.26	$14.21	$9.79
	Foothills	$59.90	$6.84	$42.96	$29.59	$26.09	$2.98	$18.71	$12.89	$33.80	$3.86	$24.24	$16.70
	Santa Ana	$55.19	$6.30	$39.58	$27.27	$26.09	$2.98	$18.71	$12.89	$29.10	$3.32	$20.87	$14.38
	SCE Rural	$72.95	$8.33	$53.87	$37.11	$26.09	$2.98	$19.27	$13.27	$46.86	$5.35	$34.60	$23.84
	Ventura	$57.57	$6.57	$41.29	$28.45	$26.09	$2.98	$18.71	$12.89	$31.48	$3.59	$22.58	$15.56
SDG&E	SDG&E	$114.15	$13.03	$84.35	$58.11	$13.84	$1.58	$10.23	$7.05	$100.31	$11.45	$74.12	$51.07

Note: assumes 2008 - 2027 project lifespan, 2.5% inflation, 8.93% discount rate, and 2008 $

As set forth in these comments, the Joint Parties believe that WDG projects can address benefit constraints associated with capacity limitations of behind-the-meter PV systems under SGIP. Renewable WDG is thereby positioned to amplify the well documented tangible and quantifiable locational T&D benefits already being reaped by DG and SGIP projects. Of course, properly compensated renewable WDG will also assure that this important market segment develops effectively so it can help to deliver the achievement of RPS objectives on schedule.

The Joint Parties strongly believe the best way for the Commission to promote renewable WDG is to encourage the utilities and developers such as GreenVolts and Cleantech to work cooperatively to identify sites that offer the greatest benefits to ratepayers, in terms of avoiding T&D investments. The MPR applicable to such renewable WDG projects should include avoided T&D costs as determined by the Commission's adopted E3 model. In order to encourage the broadest development of WDG technologies, the utilities should make public to interested parties the locations on their systems where WDG would have benefits greater than the average avoided T&D costs contained in the E3 model. Accordingly, the Joint Parties recommend that Commission direct the utilities to publish, by 31 December 2008, a list of the distribution substations on their systems where WDG would allow the utility to avoid T&D costs at least as high as those specified in the E3 model. In essence, this list would constitute a distribution-level version of the Transmission Ranking Cost Report that the utilities publish to indicate the availability and cost of bulk transmission on their systems.

VI. CONCLUSION

Renewable WDG provides significant and quantifiable locational benefits to the RPS program and to the ratepayers of California; and renewable WDG should be compensated through MPR for its true and reasonable value. This proposal addresses an existing "gap" in the CPUC's programs that encourage renewable generation. Projects in the 1 to 5 MW range are currently underserved: They exceed the qualification limits for CSI or SGIP incentives plus net metering; and they are smaller than what was envisioned with the RPS program and the large overhead costs associated with participating in the standard RPS process. Renewable WDG such as GreenVolts' solar technology can be sited in load centers on distribution systems that serve significant local loads; thereby delivering substantial locational benefits. A feed-in tariff at the MPR price and with simplified standard contracts are now available to renewable WDG projects that are 1.5 MW or smaller, which will help to alleviate transaction costs for the smallest of the renewable WDG projects, but the large costs associated with participating in RPS solicitations, and negotiating contracts with the utilities, are challenging to leverage over a broader range of project sizes, definitely including projects up to 5 MW. As such, the AB 1969 feed-in tariff provides an important model.

The MPR, however, still needs to be modified to reflect the tangible and quantifiable locational benefits of renewable WDG. Proper reflection of these tangible and quantifiable benefits will stimulate development of this highly beneficial generation; thereby delivering the advantages of the currently underserved renewable WDG market segment to California, including higher probability of achieving RPS objectives on schedule and providing both environmental and economic value to California's ratepayers. Importantly, GreenVolts and Cleantech are ready to work cooperatively with utilities to locate solar WDG where the addition of renewable peaking generation will provide the greatest benefits to ratepayers.

Finally, the Joint Parties support the comments on other 2008 MPR issues filed by other parties representing renewable and distributed generators (e.g. CalWEA/CCC/CSP).

GreenVolts, Cleantech, and Community Environmental Council appreciate the Commission's attention to these comments, and look forward to participating actively in the upcoming 2008 MPR workshop.

Respectfully submitted,

/s/ BILL BARNES
Bill Barnes
Chief Executive Officer
Cleantech America, Inc.
50 California Street, Suite 1500
San Francisco CA 94111
Telephone: 415-277-5455
Email: b.barnes@cleantechamerica.com

/s/ CRAIG LEWIS
Craig Lewis
Vice President of Government Relations
GreenVolts
50 First Street, Suite 507
San Francisco, CA 94105
Telephone: 650-796-2353
E-mail: craig.lewis@greenvolts.com

/s/ TAMLYN HUNT
Tamlyn Hunt
Energy Program Director / Attorney
Community Environmental Council
26 W. Anapamu, 2nd Floor
Santa Barbara, CA 93101
Telephone: 805-963-0583 x122
Email: thunt@cecmail.org

6 March 2008

CERTIFICATE OF SERVICE

I hereby certify that on this 6th day of March 2008, I have caused a copy of the foregoing

Pre-Workshop Comments
of GreenVolts, Cleantech America, and Community Environmental Council
on the 2008 Market Price Referent

to be served on all known parties to R0602012 listed on the most recently updated service list available on the California Public Utilities Commission website, via email to those listed with email addresses and via US mail to those without.

/s/ CRAIG LEWIS
Craig Lewis

Service List for R0602012
(last changed 4 March 2008)

dgulino@ridgewoodpower.com, ron.cerniglia@directenergy.com, rick_noger@praxair.com, keith.mccrea@sablaw.com, csmoots@perkinscoie.com, rresch@seia.org , garson_knapp@fpl.com, Cynthia.A.Fonner@constellation.com, ej_wright@oxy.com, jenine.schenk@apses.com, stacy.aguayo@apses.com, rprince@semprautilities.com, dhuard@manatt.com, rkeen@manatt.com, bill.chen@constellation.com, mmazur@3phasesRenewables.com, susan.munves@smgov.net, douglass@energyattorney.com, klatt@energyattorney.com, aimee.barnes@ecosecurities.com, pssed@adelphia.net, pssed@adelphia.net, cathy.karlstad@sce.com, william.v.walsh@sce.com, kswitzer@gswater.com, kswitzer@gswater.com, amoore@ci.chula-vista.ca.us, customerrelations@sel.com, fortlieb@sandiego.gov, khassan@sempra.com, troberts@sempra.com, email@semprasolutions.com, hharris@coral-energy.com, rwinthrop@pilotpowergroup.com, tdarton@pilotpowergroup.com, tdarton@pilotpowergroup.com, jleslie@luce.com, GloriaB@anzaelectric.org, wplaxico@heliosenergy.us, kerry.eden@ci.corona.ca.us, thunt@cecmail.org, Joe.Langenberg@gmail.com, dorth@krcd.org, jaturnbu@ix.netcom.com, pepper@cleanpowermarkets.com, marcel@turn.org, stephen.morrison@sfgov.org, gtd@cpuc.ca.gov, nao@cpuc.ca.gov, theresa.mueller@sfgov.org, mhyams@sfwater.org, ek@a-klaw.com, rsa@a-klaw.com, alhj@pge.com, crmd@pge.com, bill.chen@constellation.com, bcragg@goodinmacbride.com, jsqueri@goodinmacbride.com, jwiedman@goodinmacbride.com, jkarp@winston.com, mday@goodinmacbride.com, jkarp@winston.com, jeffgray@dwt.com, sho@ogrady.us, MAFv@pge.com, ssmyers@att.net, gpetlin@3degreesinc.com, jhamrin@resource-solutions.org, ECL8@pge.com, jchamberlin@strategicenergy.com, ralf1241a@cs.com, linda.sherif@calpine.com, jeremy.weinstein@pacificorp.com, wbooth@booth-law.com, jody_london_consulting@earthlink.net, cchen@ucsusa.org, gmorris@emf.net, ndesnoo@ci.berkeley.ca.us, clyde.murley@comcast.net, jpross@sungevity.com, tomb@crossborderenergy.com, janreid@coastecon.com, johnrredding@earthlink.net, jweil@aglet.org, demorse@omsoft.com, cmkehrein@ems-ca.com, jsanders@caiso.com, jdalessi@navigantconsulting.com, abb@eslawfirm.com, www@eslawfirm.com, Audra.Hartmann@Dynegy.com, dcarroll@downeybrand.com, dkk@eslawfirm.com, glw@eslawfirm.com, janmcfar@sonic.net, steven@iepa.com, kmills@cfbf.com, ryan.flynn@pacificorp.com, Tom.Elgie@powerex.com, sfinnerty@cpv.com, dhecht@sempratrading.com, bshort@ridgewoodpower.com, steven.schleimer@barclayscapital.com, rick_noger@praxair.com, ACRoma@hhlaw.com, perlism@dicksteinshaprio.com, MASullivan@hhlaw.com, obrienc@sharpsec.com, vsuravarapu@cera.com, porter@exeterassociates.com, tjaffe@energybusinessconsultants.com, smindel@knowledgeinenergy.com, cswoollums@midamerican.com, ssiegel@biologicaldiversity.org, abiecunasjp@bv.com, ahendrickson@commerceenergy.com, cweddington@commerceenergy.com, rmccoy@ercot.com, jsniffen@elementmarkets.com, bbaker@summitblue.com, kjsimonsen@ems-ca.com, stacy.aguayo@apses.com, dsaul@pacificsolar.net, emello@sppc.com, tdillard@sppc.com, jgreco@terra-genpower.com, elizabeth.douglass@latimes.com, harveyederpspc.org@hotmail.com,

steve@energyinnovations.com, jackmack@suesec.com, David.Townley@townleytech.com, case.admin@sce.com, frank.w.harris@sce.com, gary.allen@sce.com, woodrujb@sce.com, lizbeth.mcdannel@sce.com, rkmoore@gswater.com, Dan@EnergySmartHomes.net, amsmith@sempra.com, daking@sempra.com, lwrazen@sempraglobal.com, tcorr@sempra.com, ygross@sempraglobal.com, liddell@energyattorney.com, mshames@ucan.org, scottanders@sandiego.edu, marcie.milner@shell.com, centralfiles@semprautilities.com, jwright@semprautilities.com, dniehaus@semprautilities.com, thamilton@qualitybuilt.com, billm@enxco.com, mirwin@edisonmission.com, csteen@bakerlaw.com, rblee@bakerlaw.com, michaelgilmore@inlandenergy.com, hal@rwitz.net, mdjoseph@adamsbroadwell.com, wblattner@semprautilities.com, diane_fellman@fpl.com, nsuetake@turn.org, bfinkelstein@turn.org, Dan.adler@calcef.org, whgolove@chevron.com, dwang@nrdc.org, dcover@esassoc.com, jamesstack@fscgroup.com, filings@a-klaw.com, sls@a-klaw.com, sdhilton@stoel.com, abonds@thelen.com, brbc@pge.com, evk1@pge.com, gcooper@cpv.com, lennyh@evomarkets.com, mfalls@cpv.com, pvallen@thelen.com, RegRelCPUCCases@pge.com, spauker@wsgr.com, vjw3@pge.com, nxk2@pge.com, rreinhard@mofo.com, diarmuid@greenwoodenv.com, cem@newsdata.com, cem@newsdata.com, arno@recurrentenergy.com, jscancarelli@flk.com, judypau@dwt.com, bobgex@dwt.com, lisa_weinzimer@platts.com, cpuccases@pge.com, cmmw@pge.com, ELL5@pge.com, GXL2@pge.com, KEBD@pge.com, MMCL@pge.com, SEHC@pge.com, S1L7@pge.com, rwalther@pacbell.net, jpigott@optisolar.com, tchen@coolearthsolar.com, andy.vanhorn@vhcenergy.com, Joe.paul@dynegy.com, kowalewskia@calpine.com, duggank@calpine.com, phanschen@mofo.com, pthompson@summitblue.com, pletkarj@bv.com, philha@astound.net, dietrichlaw2@earthlink.net, alex.kang@itron.com, nellie.tong@us.kema.com, ramonag@ebmud.com, pdh9@columbia.edu, paulfenn@local.org, bepstein@fablaw.com, mrw@mrwassoc.com, cwooten@lumenxconsulting.com, rschmidt@bartlewells.com, elarsen@rcmdigesters.com, janice@strategenconsulting.com, brenda.lemay@horizonwind.com, nrader@calwea.org, rhwiser@lbl.gov, brad@mp2capital.com, michael@mp2capital.com, whitney@mp2capital.com, brian@banyansec.com, dowen@ma.org, lynn@lmaconsulting.com, keithwhite@earthlink.net, sberlin@mccarthylaw.com, davido@mid.org, tomk@mid.org, joyw@mid.org, brbarkovich@earthlink.net, rmccann@umich.edu, bdicapo@caiso.com, grosenblum@caiso.com, saeed.farrokhpay@ferc.gov, e-recipient@caiso.com, dennis@ddecuir.com, kevin@solardevelop.com, david.oliver@navigantconsulting.com, kdusel@navigantconsulting.com, cpucrulings@navigantconsulting.com, lpark@navigantconsulting.com, dougdpucmail@yahoo.com, jjg@eslawfirm.com, mclaughlin@braunlegal.com, dseperas@calpine.com, jdh@eslawfirm.com, pstoner@lgc.org, bernardo@braunlegal.com, blaising@braunlegal.com, lmh@eslawfirm.com, rroth@smud.org, mlemes@smud.org, mdeange@smud.org, vwood@smud.org, bpurewal@water.ca.gov, rlauckhart@globalenergy.com, karen@klindh.com, californiadockets@pacificorp.com, kyle.l.davis@pacificorp.com, cbreidenich@yahoo.com, dws@r-c-s-inc.com, castille@landsenergy.com, pbrehm@infiniacorp.com, ab1@cpuc.ca.gov, as2@cpuc.ca.gov, aes@cpuc.ca.gov, aeg@cpuc.ca.gov, blm@cpuc.ca.gov, bds@cpuc.ca.gov, bwm@cpuc.ca.gov, cnl@cpuc.ca.gov, dsh@cpuc.ca.gov, dot@cpuc.ca.gov, eks@cpuc.ca.gov, jm3@cpuc.ca.gov, jf2@cpuc.ca.gov, lmi@cpuc.ca.gov, mrl@cpuc.ca.gov, psd@cpuc.ca.gov, smk@cpuc.ca.gov,

svn@cpuc.ca.gov, skorosec@energy.state.ca.us, kenneth.swain@navigantconsulting.com, JMcMahon@navigantconsulting.com, gcollord@arb.ca.gov, claufenb@energy.state.ca.us, hlouie@energy.state.ca.us, hraitt@energy.state.ca.us, kzocchet@energy.state.ca.us, lgonzale@energy.state.ca.us, Mmattu@energy.state.ca.us, rmiller@energy.state.ca.us, bknox@energy.state.ca.us, hcronin@water.ca.gov

ENERGY AMERICA, LARRY EISENSTAT, RICHARD LEHFELDT, 3 PHASES ENERGY SERVICES, AOL UTILITY CORP, DONALD FURMAN, SNULLER PRICE

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Wednesday, March 10, 2010 4:34 PM ET Exclusive

SoCalEd orders 200 MW of solar panels, plans solicitation for 250 MW more

By Jeff Stanfield

Southern California Edison Co. said March 10 that SunPower Corp. won a contract to provide solar panels for up to 200 MW needed for the utility's solar photovoltaic installation program, which SoCalEd said is a major part of the largest U.S. PV program ever undertaken.

During the next five years, SoCalEd said it plans to install, own and operate 250 MW of solar generating capacity, with most of it using SunPower's panels.

Eventually, the Edison International subsidiary wants to have up to 500 MW of solar-powered generating capacity. To get to that level, SoCalEd said in a news release that it hopes to launch a competitive solicitation later this month offering long-term contracts to independent solar power providers willing to install, own and operate an additional 250 MW of photovoltaic generation and supply power to the utility.

Most of the panels of the utility-owned half of the program will be installed on large warehouse rooftops. These 1-MW to 2-MW solar installations will be connected directly to neighborhood distribution circuits where the leased rooftops are located. SoCalEd will install the panels on more than 100 rooftops, SoCalEd spokesman Gil Alexander said in an interview.

The utility is considering installing several ground-mounted stations too and for that SoCalEd is evaluating other suppliers to determine what products would best meet that need, Alexander said.

The estimated cost of the utility-owned installations is $875 million, excluding future operation and maintenance expenses Alexander said.

"We told regulators two years ago we believe we can do it for $3.50 per installed watt," Alexander said. "This project was developed to deliver solar photovoltaic energy in California for half the prevailing cost of that technology. Today's announcement helps us keep that promise."

The solar stations will be mounted primarily on rooftops in Riverside and San Bernardino counties and mostly in the Inland Empire region in locations where power is most needed to meet growth, he said.

Primarily, the buildings will be warehouses where energy needs are minimal and where the owners do not have incentives to participate in the California Solar Initiative, or CSI, which provides incentives for customers to mount their own rooftop solar systems, Alexander said.

This program will have no relation to the CSI program, as the costs of the utility-owned installations and the power purchase agreements with independent solar developers will be recovered in customer rates, he added.

"It is not like building owners getting financial incentives and installing solar panels on their roof to offset power bills," Alexander said. "These will be buildings with low energy demand where the owner would not otherwise think seriously about adding solar themselves because the gain does not pencil out."

Instead, the building owners will get money from SoCalEd for leasing their rooftops in long-term agreements.

The SunPower T5 Solar Roof Tile integrates into a single unit a solar panel, frame and roof mounting system, thereby reducing installation time and costs, SoCalEd said. In addition, the SunPower product was selected because it will produce more power per installation, the utility said.

Alexander said the integrated panel and roof mounting is a primary consideration for reducing rooftop installation costs, but that for ground-mounted units, the integrated roof system has no bearing so other suppliers are being considered for the remaining 45 MW of utility-owned systems. SunPower panels had already been selected for the first 5 MW of utility-owned systems.

For the competitive solicitation, the California Public Utilities Commission on Jan. 21 approved a process to be used for the second track of SoCalEd's photovoltaic program. The commission directed SoCalEd to conduct a

competitive solicitation offering long-term power contracts to independent solar power providers willing to install an additional 250 MW of photovoltaic generation.

Alexander said the cost of the competitive half of the program will not be determined until winning bidders are chosen. SoCalEd expects this fall to determine the winning bidders and submit contract proposals to the PUC for approval. A specific dollar amount will be kept confidential, but Alexander said his company will say whether the costs come in above, below or equivalent to the utility-owned projects.

The request for proposals will follow the same model of any California renewable energy solicitation, he said, and will be counted toward meeting SoCalEd's renewable portfolio standard obligations.

The utility's grid engineers will study the electrical effects of a high penetration of photovoltaics on distribution circuits and adapting circuits to accommodate these large installations. The information gained will be shared with the power industry, SoCalEd said.

SoCalEd has already installed two rooftop solar projects in Fontana, Calif., and Chino, Calif., and is within days of announcing a third project in the Inland Empire, Alexander said.

With two major seaports, Los Angeles and Long Beach, Calif., are major shipping centers and the region has many warehouses with expansive flat roofs covering many acres of real estate. ProLogis, the world's largest owner, manager and developer of distribution facilities, hosted SoCalEd's first rooftop installation at Kaiser Distribution Park in Fontana, and owns 180 distribution facilities in SoCalEd's territory.

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SNL Financial LC, One SNL Plaza, PO Box 2124, Charlottesville, Virginia 22902 USA, (434) 977-1600

Application No:	A.
Exhibit No.	SCE-1
Witnesses:	R. Fisher D. Klun M. Nelson R. Perez G. Rodrigues D. Snow

SOUTHERN CALIFORNIA
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(U 338-E)

Solar Photovoltaic (PV) Program Testimony

Before the

Public Utilities Commission of the State of California

March 27, 2008
Rosemead, California

1469812

Solar Photovoltaic (PV) Program

Table Of Contents

Section	Page	Witness
I. INTRODUCTION AND OVERVIEW	1	M. Nelson
II. NEED FOR PROGRAM	3	
A. Implementation Of SCE's Proposed Large Solar PV Program Will Contribute To State Goals To Promote Both Solar PV and Renewable Power	3	
B. SCE Can Best Develop Solar PV Program	7	
1. System Operation And Integration Into The CAISO System	7	
2. Customers Receive Credit For Solar PV Output	7	
3. Existing Business Relationships And Resources Can Be Leveraged	8	
4. SCE's Extensive History And Experience With Solar Generation	9	
C. SCE's Solar PV Program Will Increase The Probability That The Million Solar Roofs Goal Will Be Met	11	
D. Solar PV Program Can Improve Efficiencies of Elements Of The California Solar PV Market To Reduce Costs	12	
E. The Solar PV Program Will Provide Unique Benefits And Challenges From the Addition Of Large Amounts of Solar PV To SCE's System	15	
F. The Solar PV Program Will Provide Valuable Information To The State	17	
1. Information On Interaction Of Solar PV With The Distribution System	18	
2. Information And Experience Forecasting Solar PV Output	19	
3. Information On Workforce Training	19	
4. Information On Streamlining Of Tariff Applications For Solar PV	19	

Solar Photovoltaic *(PV) Program*

Table Of Contents (Continued)

Section	Page	Witness
III. PROGRAM DESCRIPTION	20	R. Perez
A. Size of Program	20	
B. Length of Program	20	
C. Description of Facilities	22	
1. Type of Facilities	22	
a) Crystalline Technology	22	
b) Thin Film Technology	24	
c) Technology Comparison	26	
d) Inverters and Balance of System	27	
e) PV Module Mounting Systems	28	
f) Building Integrated PV	30	G. Rodrigues
2. Size of Facilities	32	R. Perez
3. Location and Configuration of Facilities	33	
4. Interconnection Facilities	35	
5. Data Acquisition System (DAS)	37	
6. Leasing Rooftop Space For Facilities	38	
IV. PROGRAM COST ESTIMATE	40	
A. Capital	40	
1. Generating Facilities Cost	40	
2. Installation Cost	40	
3. Interconnection Costs	42	
4. Total Program Capital Costs	42	
B. Operation & Maintenance Cost	44	
1. Roof Lease Payments	44	

Table Of Contents (Continued)

Section	Page	Witness
2. Maintenance Cost	45	
3. Staffing	45	
V. RATEMAKING	48	D. Snow
A. Introduction	48	
B. Forecast of SCE's Solar PV Program Revenue Requirements	48	
1. Capital Expenditures/Additions	50	
2. Depreciation Expense	51	R. Fisher
a) Generating Facilities Plant	51	
(i) PV Modules and Balance of System Components	51	
(ii) PV Rack	53	
b) General Plant	53	
c) Distribution Plant	53	
3. Rate of Return	54	D. Snow
4. O&M Expense	54	
5. Income Taxes	55	D. Klun
C. Description of Solar PV Program Balancing Account (SPVPBA)	56	D. Snow
D. Proposed Reasonableness Review and Standard for Reasonableness Review	57	
1. Inflation Adjustment	58	P. Hunt
2. Reasonableness Review Procedure	58	D. Snow
Appendix A Witness Qualifications	60	

Solar Photovoltaic (PV) Program

List of Tables

Section		Page

Table II-1 Typical Residential Solar PV Installation (3 kW +/- 0.05).....9

Table II-2 Typical Large Residential Solar PV Installations (900 kW – 1MW).....9

Table III-3 Estimated Solar PV Program Schedule.....22

Table IV-4 Estimated Hardware Cost for 1 MW Solar PV Project (2008$).....40

Table IV-5 Estimated Installation Cost for 1 MW Solar PV Project (2008$).....41

Table IV-6 Summary of Capital Costs of Solar PV Program (2008$).....43

Table IV-7 Estimated Yearly O&M Costs for a 1 MW Solar PV Project (2008$).....45

Table IV-8 Solar PV Program Management Labor Forecast Increase For New Employees (2008$).....46

Table IV-9 Forecast Summary of Staffing Costs of Solar PV Program.....47

Table V-10 Summary of Solar PV Program Estimated Revenue Requirements (O&M and Capital Costs) Thousands of Dollars.....49

Table V-11 Summary of Solar PV Program Calendar Year Capital Expenditures $millions.....51

Table V-12 Summary of Future Decommissioning Expenses (included in Depr. Expense) thousands of dollars.....52

Table V-13 Summary of Solar PV Program Calendar Year Estimated O&M Expenditures $millions.....55

Table V-14 Reasonableness Review Threshold For Direct Solar PV Program Capital Costs (2008$).....58

List of Figures

Section		Page

Figure II-1 Chart of Solar PV Output vs. Time of Day Center for the Study of Energy Markets, 2005 16

Figure III-2 Typical Crystalline Solar PV Module 175 watts measuring approximately 64”x 32” x 1.75” and weighing 33 pounds 23

Figure III-3 Typical Amorphous Thin Film Module Measuring 18 feet long by 15.5” wide and Weighing_17 lbs. 25

Figure III-4 Typical Rigid Thin Film PV Module Measuring 4 feet long by 2 feet wide and Weighing 26.5 lbs. 26

Figure III-5 500kW ac Inverter and Transformer Inverter measuring 7.6”x9.6’x3’6” (HxWxD) transform measuring 5’x4’x4’ (HxWxD) and weighing combined approximately 9,800 pounds. 28

Figure III-6 1.2 MW Non-Penetrating Solar PV System on Commercial Rooftop in Sacramento, CA 30

Figure III-7 Photograph of the Long Beach Convention and Entertainment Center illustrating the solar PV array is not visible from street level 33

Figure III-8 Proposed System Single Line Simplified Interconnection 37

Figure III-9 Proposed System Single Line Complex Interconnection 37

I.

INTRODUCTION AND OVERVIEW

California is endowed with abundant solar resources. In recent years, the State has taken bold steps to develop this resource, but more can be done. In this application, Southern California Edison Company (SCE) proposes the Solar Photovoltaic (PV) Program, an aggressive program to develop up to 250 megawatts (MW)[1] of utility-owned Solar PV generating facilities ranging in size from 1 to 2 MW[2] each. This program is targeted at the vast untapped resource of commercial and industrial rooftop space in SCE's service territory.[3] It will aggressively bridge the gap between small and large scale solar installations. It will also use rooftop space from entities that would not otherwise be typical candidates for the net energy metering tariff.[4] SCE proposes to develop these projects at a rate of approximately 50 MW per year at an average cost of $3.50/Watt (W). If the program is successful, SCE may seek additional authority to expand the program to 500 MW. An expansion to 500 MW would seek to maintain the momentum of that success. So, there is no hiatus in installing new systems. SCE's proposed Solar PV Program is a near-term bold step to further develop California's solar resources independent of the need for major new transmission facilities.

California has implemented an aggressive program, the California Solar Initiative (CSI), to facilitate the development of solar projects. The Renewable Portfolio Standard (RPS) also facilitates development of solar projects, along with other renewable resources. But these programs have left a large solar gap. As described in detail below, SCE's Solar PV Program is uniquely qualified to fill this

---

[1] Unless otherwise specified, any reference to energy output in this filing follows the common convention within the PV industry, which is to refer to output as PV panel direct current (dc) output. Additionally, SCE proposes using installed dc output in reasonableness reviews because installation occurs in dc panels. Based on sample calculations, the conversion factor of 0.90 will convert from MW dc to MW alternating current (ac) using the California Energy Commission's ac MW conversion (i.e., multiply MW dc by 0.90 to obtain MW CEC-ac Rating).

[2] SCE envisioned the individual Solar PV Program installations to range from 1 to 2 MW. As the program proceeds, however, some installations may be larger or smaller than this range due to roof size, circuit loading, optimal use of inverters or other considerations.

[3] While SCE presently intends the program for rooftops, SCE may pursue other locations and opportunities for placement of Solar PV facilities.

[4] Net energy metering installations, which are limited to 1 MW, allow utility customers to receive California Solar Initiative (CSI) incentives and off-set their energy usage by their solar PV system output over a 12-month period.

gap, because this bandwidth (1 to 2 MW facilities) of the solar resource is going untapped. There is currently no program in place to develop this market segment. By further developing this aspect of the solar market, the Solar PV Program will contribute in the near term to achieving the State's CSI million solar rooftop goals. It will also contribute to meet renewable goals.

Furthermore, SCE anticipates that the aggressive development of this "middle market" for solar PV in southern California will attract investment, manufacturing, and expertise to California's solar industry. This will increase supply options and should reduce the cost for all solar PV products and services. In turn, broadening and deepening the local solar PV market will produce savings in the State's CSI program. Simply stated, reducing the installed cost of solar PV will leverage the subsidy dollars already allocated to the CSI program and produce more capacity and energy deliveries for California's investment in solar PV.

Finally, SCE is uniquely qualified to develop this market sector. These facilities will interconnect at the utility distribution level and will be sited at SCE retail customer locations. SCE's strong balance sheet, institutional expertise, and SCE's long history of solar "firsts" makes it a logical candidate to pioneer innovations in the untapped industrial and commercial rooftop market through this program.

II.

NEED FOR PROGRAM

A. Implementation Of SCE's Proposed Large Solar PV Program Will Contribute To State Goals To Promote Both Solar PV and Renewable Power

In 2006, Governor Schwarzenegger, working with the Commission and the California Legislature, established a CSI designed to develop 3,000 MW of rooftop solar PV installations by 2016. The State has authorized substantial incentives to achieve this aggressive target of 1 million rooftop solar installations.

Solar is a renewable resource. The State has adopted one of the most aggressive RPS programs in the country. The goal is to have 20% of SCE's customers' energy needs met with renewable resources.[5] Although not specifically targeted at solar resources, the RPS program has the potential to yield substantial development of large central-station solar resources over the next decade. Several large-scale, central station solar installations are under contract or in development as a result of SCE's RPS program solicitations.

But these programs have left a large solar gap. California's CSI is geared to develop very small solar PV installations. California's RPS program is geared to develop very large solar (not necessarily PV) installations. Neither program, however, is well suited to develop medium-scale PV solar installations in the 1 to 2 MW range in the near-term due to size and transmission limitations. And although the economics of 1 to 2 MW PV facilities are far superior to typical rooftop facilities, they are too large to take full advantage of the State's CSI and net energy metering[6] programs. Many large commercial rooftops have site electrical loads that do not match the energy production of a 1 to 2 MW

---

[5] Public Utilities Code Section 399.15(b)(1) sets forth a goal that 20% of retail electric sales be served by renewable resources by 2010:

> Each retail seller shall, pursuant to subdivision (a), increase its total procurement of eligible renewable resources by at least an additional 1% of retail sales per year so that 20% of its retail sales are procured from eligible renewable energy resources no later than December 31, 2010…

[6] Net energy metering installations are limited to 1 MW. Distributed Generation installations that receive CSI or Self Generation Interconnection Program (SGIP) funds are limited to 5 MW in size, but may receive incentives for up to 1 MW under CSI even if they received 1 MW under SGIP for a potential total incentives of 2 MW per site.

solar PV facility. Conversely, other utility-scale solar technologies, such as parabolic trough, Stirling dish and "power tower" installations are not commercially practicable in distributed configurations, urban and semi-urban locations, or at the 1 to 2 MW scale. SCE's Solar PV Program fills this solar gap. There is currently no other program in place to develop this important market sector. SCE proposes immediate start-up of the Solar PV Program to bridge the solar gap and to assist in meeting the State's renewable goals.

SCE's Solar PV Program is targeted at the vast untapped resource of commercial and industrial rooftop space in SCE's service territory. This program will aggressively bridge the gap between small and large scale solar installations. Although this program will focus on a fertile market sector undeveloped by either the CSI or RPS programs, the program will contribute to both goals. In CSI terms, this program has the potential to add over 80,000 "rooftop equivalents"[7] in five years or about 10% of the overall CSI goal of 1 million rooftops. SCE's program will also contribute in the near term to achieving the State's renewable energy goals. Because these installations will interconnect at the distribution level, they can be brought on line relatively quickly without the need to plan, permit, and construct the transmission lines. Larger scale renewable resources generally require transmission line construction to deliver their output to load centers.

SCE is currently pursuing transmission line permitting and construction as one way to help the State meet its renewable energy goals. In addition, SCE's actions to implement its Long Term Procurement Plan (LTPP) and RPS procurement activity are consistent with meeting the renewable goals. Decision No. (D.)06-05-039 states that "…, we will take into account whether or not each electrical corporation undertook all reasonable actions to comply [in meeting the State's renewable energy goals]. One of those actions is building, then owning and operating the [renewable] resource itself."[8] In addition, D.07-02-011 and D.08-02-008[9] stated that, "…we encourage IOUs to actively

[7] The State's CSI goal of 3,000 MW by 2016 is based on an average PV installation size of 3 kW, yielding 1 million rooftops. A "rooftop equivalent" is 3 kW. SCE's program goal of 250 MW installed by 2013 yields 83,333 rooftop equivalents.

[8] D.06-05-039, *mimeo*, p. 34.

[9] D.07-02-011 dated February 15, 2007, *mimeo*, p. 25 and D.08-02-008, *mimeo,* p. 33.

assess the feasibility of utility ownership, and pursue such ownership when and where it makes sense." While the primary purpose of the program is to help meet the State's ambitious solar roof goals, the Solar PV Program will also add to SCE's renewable portfolio in response to these challenges. Specifically, in 2009, the Solar PV Program installations will produce 0.1% of SCE's customer energy needs; by 2014, Solar PV Program installations will produce approximately 0.4% of SCE's customer energy needs. To assure the availability of this generation as soon as possible after approval of this application, SCE may begin implementation of the Solar PV Program in 2008, while awaiting a final Commission decision on this application.

The CPUC has articulated various policies that solar PV supports and advances. SCE's proposed Solar PV Program would advance the following policies adopted in D.06-01-024, implementing the CSI Program:[10]

- Development of solar technologies is consistent with state policy and provides California with a clean and reliable source of distributed energy.[11] SCE's proposed Solar PV Program will provide California with a clean and reliable source of distributed energy.
- The legacy California Energy Commission (CEC) and CPUC solar incentive programs, the Emerging Renewable Program, and the Self Generation Interconnection Program (SGIP), and the new CSI Program, although similar, provide incentives to different-sized projects and are funded by different utility rate components.[12] SCE's proposed Solar PV Program will be utility-owned. The Solar PV Program will produce energy from eligible renewable resources[13] for

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[10] The CSI Program provides detailed requirements for receiving funding for the installation and operation of solar PV projects under the Commission's incentive program. As authorized by the Commission and SB 1, Chapter 132, Statutes of 2006 (SB1, Murray), the CSI Program has a total budget of $2.1672, D. 06-12-033, December 14, 2006, *mimeo*, p. 27, billion to be used over 10 years, D. 06-08-028, August 24, 2006, *mimeo*, pp. 83, 88.

[11] D.06-01-024, dated January 12, 2006, Finding of Fact No. 1, *mimeo,* p. 39.

[12] Id. at Finding of Fact No. 2, *mimeo*, p. 39.

[13] An eligible renewable energy resources uses biomass, solar thermal, photovoltaic, wind, geothermal, fuel cells using renewable fuels, small hydroelectric generation of 30 megawatts or less, digester gas, municipal solid waste conversion, landfill gas, ocean wave, ocean thermal, or tidal current. The term "eligible renewable energy resource" is further defined in California Public Utilities Code Section 399.12(c) and California Public Resources Code 25741(b).

SCE's customers. To the contrary, incentive programs give the customer generator the renewable energy credit which is not currently eligible for use in California.

- A 10-year commitment by the state to provide incentives for solar installations provides a signal to manufacturers and other industry participants that encourages innovation and development.[14] SCE's proposed Solar PV Program will provide a signal to industry participants that large-scale solar PV projects on commercial-size roofs are a viable power source. This will transform the market for installation of such projects without depending on incentives.
- All solar energy technologies have the potential to reduce demand for fossil fuels and investments in more traditional energy resources and provide environmental benefits.[15] SCE's proposed Solar PV Program also has the potential to reduce demand for fossil fuels.

SCE proposes this program in furtherance of the State's goal to increase the installation of solar PV technology. Our proposed program will achieve this goal at lower cost and will further help jump-start the solar industry. The cost to our customers of the Solar PV Program will be significant, but far less than the cost of CSI implementation.[16] For these reasons, if the CSI goals become mandatory for SCE's customers, SCE requests that the MWs installed under its program be "credited" towards its customers' targets. In addition, the cost impact on our customers is not insubstantial. They already bear the annual cost of the CSI program and the carrying costs of the Solar PV program if SCE's application is granted. This may justify reducing their share of the State's CSI goals and potentially some portion of the CSI program costs our customers contribute.

SCE proposes a base case budget of about $875 million and a reasonableness threshold of $962.5 million to be used over 5-years to produce 250 MW of solar PV power. SCE's program will improve the efficiency and increase use of solar PV consistent with State goals and policies.

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[14] Id. at Finding of Fact No. 4, *mimeo,* p. 39.

[15] Id. at Finding of Fact No. 5, *mimeo,* p. 39.

[16] See Section II.B.3, infra.

B. SCE Can Best Develop Solar PV Program

1. System Operation And Integration Into The CAISO System

SCE, as operator of its distribution system, has the technical expertise to evaluate the various solar PV technologies and their impacts on its distribution system. SCE will study solar PV panel and inverter efficiency. SCE can monitor system status and cost-effectively facilitate repair of these systems through its field personnel. SCE is the only California Independent System Operator (CAISO) participant scheduling solar resources into the CAISO electric grid. SCE is very aware of the challenge solar generated electricity creates. Solar PV resources over 1 MW must schedule power with the CAISO and will likely participate in the CAISO's Participating Intermittent Resource Program (PIRP).

The current PIRP does not include solar resources. SCE will work with the CAISO to formulate protocols, data acquisition system requirements and forecast methods for solar PV resources just as SCE has done with the wind PIRP. The Solar PV Program will provide SCE with operational control of a utility-owned solar generating resource. This will greatly facilitate development of a solar PIRP.

2. Customers Receive Credit For Solar PV Output

Solar PV output is eligible to be counted towards the State's renewable goal of meeting 20% of customers energy needs with renewable resources. However, utilities and their customers do not receive credit for the output associated with Solar PV projects installed pursuant to the State's CSI program, as the customer/owner of the PV facility retains the renewable energy credit.[17] Solar PV installed by SCE under the Solar PV Program will count towards SCE's RPS goals. The Solar PV Program would provide 50 MW each year for 5 years. A generating facility with a 45 MW capacity and an 18% capacity factor is expected to generate 70,956 MW[18] per year. In 2009, this would equate to approximately 0.1% of SCE's customer energy needs. A generating facility with a 225 MW capacity

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[17] See, D.07-01-018, *mimeo*, p. 20 and Ordering Paragraph 1, *mimeo*, p. 31..

[18] Expected generation shown is assumed to be ac MWh like any other generation SCE procures under the RPS program.

and an 18% capacity factor is expected to generate 354,780 MWh[19] per year. In 2014, this would equate to approximately 0.4% of SCE's customer energy needs. This supports the State's overall goals.

3. Existing Business Relationships And Resources Can Be Leveraged

SCE has established electricity supply relationships with potential vendors and commercial building lessors who are also its customers. These entities see SCE as a reliable business partner, in part because SCE has been in business for over 100 years. SCE's utility operations are viewed as a stable, competent, and reliable. SCE's strong balance sheet and procurement expertise allow the utility to readily negotiate contracts with rooftop owners and vendors. SCE expects to receive volume discounts for its proposed investment. Multiple developers are unlikely to achieve the same efficiencies and favorable pricing levels. Because of these established relationships and volume discounts, SCE can move quickly and efficiently to develop the Solar PV Program.

SCE can expand solar PV implementation at a lower cost than is currently in effect for CSI customers. Tables II-1 and II-2 below compile CEC data from CSI Photovoltaic Installation Applications from January 1, 2007 to March 1, 2008. The chart compares total installed costs for residential (3 kW nominal size) and large commercial (900kw to 1 MW size) solar PV projects. On average, residential solar PV installations cost $8.25/W, while large commercial installations cost $6.78/W. SCE's Solar PV Program budgeted cost is $3.50/W on average and proposed reasonableness threshold is $3.85/W on average. SCE expects to achieve these substantially lower installed costs through the volume of the proposed projects creating economies of scale and by partnering with PV suppliers providing newer technologies at considerable cost savings.

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[19] Id.

Table II-1
Typical Residential Solar PV Installation (3 kW +/- 0.05)

Utility	#	Average Total Cost	Average Nameplate Rating (kW)	Average Cost per Watt ($/W)
SCE	42	$24,206	3	$8.07
PG&E	103	$25,625	3	$8.54
CCSE	11	$24,591	3	$8.22

Table II-2
Typical Large Residential Solar PV Installations (900 kW – 1MW)

Utility	#	Average Total Cost	Average Nameplate Rating (kW)	Average Cost per Watt ($/W)
SCE	29	$7,617,496	1,165	$6.56
PG&E	28	$8,191,391	1,160	$7.08
CCSE	5	$7,698,611	1,190	$6.47

4. SCE's Extensive History And Experience With Solar Generation

In addition to its location, strong balance sheet and institutional expertise, SCE's long history of solar "firsts" makes it a logical candidate to pioneer innovations in the untapped industrial and commercial rooftop market. Among other things, SCE developed and operated the groundbreaking 10 MW Solar One project as the first utility solar "power tower" in the 1980s. SCE followed up with the

Solar Two project in the 1990s that demonstrated 28 hours of continuous grid connected generation from solar power tower technology using molten salt energy storage technology. This is a world record that still stands today. This storage technology is now being deployed as an important component of today's larger solar generating stations being built in Spain and of those proposed for California and Arizona.

In partnership with McDonnell Douglas, SCE also developed the 25 kW Stirling dish technology. This project set a world record for efficiency, converting solar energy into electricity at a rate of 29.4% in 1984. SCE sold this technology to Stirling Energy System (SES) in 1996 and just this year SES and Sandia National Laboratory announced a new world record for efficiency, converting the sun's energy into useable electricity at 31% efficiency. This would not have been possible without the years of SCE's pioneering effort in the 1980s.

SCE also partnered with ARCO Solar to build and operate the first large, 1 MW, solar PV array that used concentrating lens technology. SCE was lead contractor for the CEC PIER program that installed and monitored more than a dozen rooftop solar PV systems in the early to mid-1990s. This proved that grid-connected solar PV was feasible. In addition, SCE installed highly visible demonstration solar PV projects located at the Santa Monica pier and the South Coast Air Quality Management District's (SCAQMD) "solar carport." The distribution circuit unloading project installed at the Huntington Library using solar PV to defer an underground cable replacement was also a first.

SCE also has Power Purchase Agreements (PPAs) for 359 MW ac nameplate capacity with the nine Solar Energy Generating Station (SEGS) facilities that have been operating for over 20 years in the Mojave Desert. Presently, these are the only PPAs producing thermal solar generated electricity in California and represent the vast majority of the solar production in the nation today.[20]

Finally, in the 1990s, SCE pioneered flexible PV with Texas Instruments and also provided two solar PV retail tariffs to support the Solar Neighborhoods program.

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[20] Nevada Solar One, a 64 MW SEGS technology solar facility, commenced operation in June, 2007. APS also operates a 1 MW test facility which went into service in 2007. This makes total installed and operating concentrating solar power technology nameplate capacity 424 MW.

Over the course of nearly 30 years, SCE has developed a broad institutional knowledge from its relationship with sellers as well as from operating just about every solar generating technology. This knowledge and experience will form a strong foundation for the Solar PV Program. As indicated above, the Solar PV Program will provide about 0.4% of SCE's estimated customer energy needs in 2014.

C. SCE's Solar PV Program Will Increase The Probability That The Million Solar Roofs Goal Will Be Met

In the LTPP proceeding, the Commission found that:

> "If an [Investor-Owned Utility (IOU)] proposes a [Utility-owned Generation] project outside of a competitive [Request for Offers (RFO)], it is reasonable to require the IOU to make a showing that holding a competitive RFO is infeasible."[21]

According to California Solar Initiative (CSI) data, more than 40% of the applications for projects over 900 kW in SCE's service territory have been cancelled or suspended since CSI was implemented in January 2007.[22] SCE has the financial stability and business reputation that will enhance the development opportunities for solar installations generally. The Solar PV Program provides utility customers and the State a substantial increase in the probability that 250 MW of solar PV systems will be available to meet the State's goals over the next five years.

Large PV Projects installed by independent power producers provide valuable information for those firms involved in the project, but less value to the State or the PV industry as a whole. SCE plans to share the information it gains through the installation and operation of Solar PV Program. This type of information gathering and technology assessment associated with the solar PV technology is inconsistent with the concept of private-party completion and low bidders. If the Commission wishes to jump start the competitiveness of roof top solar PV as a renewable resource, SCE's Solar PV Program will further that goal. It will thoroughly evaluate solar PV technology and will support greater efficiency in the California solar PV market.

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[21] D.07-12-052, Finding of Fact No. 100, *mimeo,* at p. 286, p. 2, and fn. 240, p. 210.

[22] These are mostly legacy SGIP solar PV installations. The SGIP for solar PV was rolled into the CSI in January 2006.

SCE is currently developing the procurement process for the PV Systems (i.e., PV panels, inverters, balance of plant), installation, and leasing of the roofs. SCE will rely heavily on competitive solicitations for most procurement activities. This will provide the most cost-effective solution for our customers. Because the Request for Proposals (RFP) process is lengthy, SCE may issue directed purchase orders to selected vendors to expedite the initial installations in parallel with the overall program competitive solicitations.

D. Solar PV Program Can Improve Efficiencies of Elements Of The California Solar PV Market To Reduce Costs

SCE proposes to pursue large-scale implementation of 50 MW of solar PV projects of 1 to 2 MW on commercial rooftops each year for five years. SCE seeks to create efficiencies in the California market for solar PV equipment and installation resources, but not to overheat the market for solar PV panels, equipment, and installation resources. In SCE's judgment, 50 MW per year will trigger new efficiencies, but not drive prices up due to materials shortages or lack of manufacturing capacity.[23] The solar PV modules required for the Solar PV Program will not impact product availability for other solar PV facilities in California. During the last several months, the solar PV module manufacturers have made significant progress towards securing critical materials, such as silicon, needed to meet product demand. The largest solar PV module manufacturers are adding production lines to meet demand. New solar PV module manufacturers located overseas continue to enter the U.S. market. Additionally, emerging technologies using new materials are on the verge of commercial viability.

The Solar PV Program system installations can begin a few months after regulatory approval or even earlier with implementation of a memorandum account prior to final Commission approval. The Solar PV Program will aid the market for rooftop solar PV generation. The goals are to drive installation costs down, improve technology and pricing of certain component parts, increase installation

[23] If the program is successful, SCE may seek Commission authority to increase the overall size of the Solar PV Program to 500 MW. The additional 250 MW would likely be realized through the combination of installing more MW per year and lengthening the program term itself.

efficiency, and improve installation methods. Another related goal is to develop a trained in-state installation work force.

SCE's installations of 1 to 2 MW projects totaling up to 50 MW each year should help to (1) refine production of solar PV system parts, (2) improve the capabilities of ancillary equipment, such as inverters, (3) increase the use of otherwise vacant large commercial rooftops in California, and (4) increase the efficiency of installation. To meet Solar PV Program goals, SCE will order large volumes of solar PV panels, mounting, and electrical hardware each year. The increased scale of manufacturing required by such orders should lead manufacturers to improve designs and to increase their capability to produce such parts. Manufacturers will likely also have the incentive to improve manufacturing processes to incorporate economies of scale that drive prices down.

SCE expects to order, on average, 50 MW in nameplate rating of large-scale inverters each year. This will provide incentives to improve inverter technology. Improvements in technology are possible through SCE coordination with inverter manufacturers. Solar data that SCE collects may suggest design changes to inverters that could enhance PV performance. SCE could then coordinate with inverter manufactures to implement these design changes. For example, if data collection and subsequent analysis suggest solar inverters could cost-effectively add voltage support, manufacturers could design future inverters to do so. Improvements in technology are always possible. But through SCE participation in code committees and interconnection tariff rules establishing the standards for inverters designed and certification, SCE can help facilitate more ready acceptance of changes.

SCE plans to interconnect 50 MW of these projects with the distribution grid each year. This will help: (1) refine the engineering and physical processes for 1 to 2 MW solar PV systems interconnections, and (2) reduce the time and cost of implementing such interconnections. SCE will refine the interconnection process by standardizing engineering and design, training specialized labor, and interacting with building and interconnection code agencies as needed to improve efficiency while

still maintaining safety. This supports California's goals as listed in the CEC's PIER[24] Renewable Energy Technologies Program Solar PV Research Plan ("CEC PV R&D Plan") dated September, 2007, of "improving [PV] education, including updating training for solar PV installers, building code officials, architects, and other building personnel. Milestones emphasize the creation and/or improvement of standards for buildings, energy efficiency, and module certification to ensure consistency and high performance."

SCE anticipates initially contracting with owners of large commercial rooftops. Some rooftop owners may not initially see the benefits of solar PV. SCE's initial installations will demonstrate to all large commercial rooftop owners the benefits of utility ownership arrangements and should widen acceptance of similar leases. The important difference between this program and the current third-party ownership with PPAs is that the commercial building tenant (host customer of the PPA) is not a party to the business arrangement. This relieves the commercial building owner from the concern over liability to the solar PV owner about host customer failure to pay for electricity deliveries under the PPA. The utility-owned and leased rooftop business model allows the solar PV facility to deliver electricity directly to the utility. This simplified arrangement will reduce the price of solar PV generated electricity delivered to the grid. Because it is a direct transaction with the utility, it will bypass net energy metering costs.

SCE's Solar PV Program should also expand the number of skilled workers by increasing the total number of PV installations. This expanded number of skilled workers should gain greater efficiency and knowledge simply by repetitively performing installations. Currently, labor is about 20% of the cost of solar PV installations. If the Solar PV Program leads to improving the efficiency of workers, SCE's Solar PV Program should reduce costs of solar PV installation while creating skilled jobs within the State.

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[24] PIER is the CEC's Public Interest Energy Research group which conducts ratepayer funded studies into various advanced technology areas, including renewable energy technologies and environmentally preferred advanced generation.

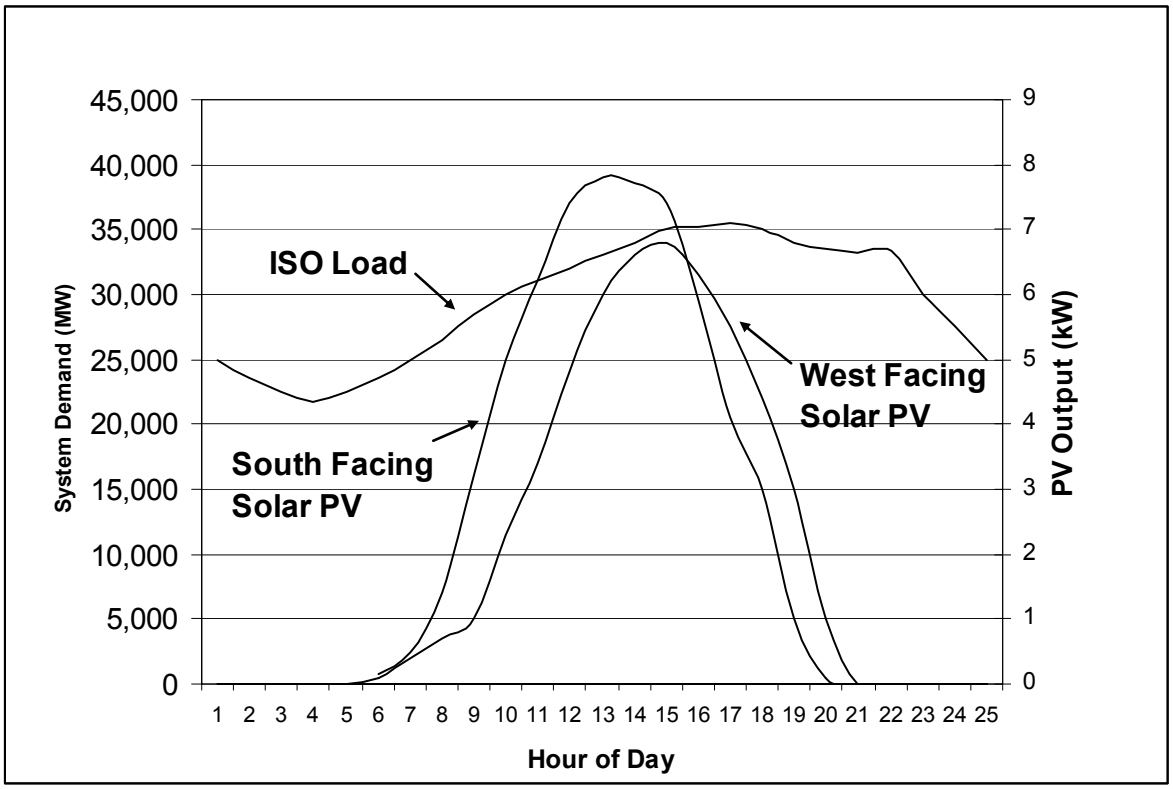
SCE intends to improve the efficiency of the California rooftop solar PV market by increasing the number of 1 to 2 MW solar PV systems. Utilities will also have the opportunity to apply this experience gained in California throughout the United States.

E. The Solar PV Program Will Provide Unique Benefits And Challenges From the Addition Of Large Amounts of Solar PV To SCE's System

Solar PV is a form of distributed generation. As such, it has unique benefits and challenges. SCE will not need to construct new transmission lines to interconnect the distributed solar PV projects contemplated by the Solar PV Program. These systems will interconnect directly with the distribution system. In addition to increasing the amount of renewable energy and reducing greenhouse gas (GHG) emissions, the Solar PV Program should also help determine: (1) how large numbers of these 1 to 2 MW solar PV projects affect the reliability and stability of SCE's distribution grid, and (2) whether such installations can be relied upon to support generation requirements when it is needed, especially on hot, summer days.

Solar PV power may follow the system load better than other intermittent resources. Solar PV energy has historically been higher on clear summer days, which is when the system needs increased generation. Depending on the technology being employed, solar PV output will decrease to a varying degree as temperatures increase. During summer months, higher temperatures might be a deciding factor in technology selection for a given site. Also, as Figure II-1 shows, solar PV power provides significant output when load on SCE's system ramps up. Solar PV does not normally peak simultaneously with load, as load normally peaks in late afternoon when solar PV output begins to decline. As a result, SCE may opt to install some PV systems in a west-facing orientation to maximize the later afternoon output and thus the value to the grid.

Figure II-1
Chart of Solar PV Output vs. Time of Day
Center for the Study of Energy Markets, 2005



Significant amounts of solar PV output will affect the net load profile characteristic for the circuits on which a Solar PV Program facility will be located. This effect on the net load profile characteristics will be an important finding of this program.

SCE can coordinate the Solar PV Program with customer demand shifting using existing SCE demand reduction programs on the same circuit. This will create more fully utilized distribution circuit assets. Without such coordination, much more distribution equipment may be needed to allow solar PV deployment beyond the current Rule 21 guidelines for individual circuits. SCE is uniquely situated to combine Solar PV Program generation, customer demand programs, and advanced distribution circuit design and operation into one unified system. This is more cost effective than separate and

uncoordinated deployment of each element on separate circuits. SCE also can coordinate generation or storage technologies at the substation level to moderate the inherent weather-caused variability in solar PV production before such intermittency cascades into the higher voltage CAISO-controlled transmission system. Such coordination will reduce system costs.

The State's regulatory agencies identified preferred resources in the Energy Action Plan (EAP), in the order of: "energy efficiency, demand response, renewables, distributed generation and clean fossil-fuel."[25] Solar PV is a renewable resource and is a preferred resource under the EAP. The Solar PV Program will be a renewable distributed generation resource.

Solar PV is also a flexible resource. SCE can place solar PV generating facilities in areas where air quality is designated as highly-sensitive by the South Coast Air Quality Management District (SCAQMD), as solar PV has no emissions. Many highly-sensitive SCAQMD areas are also areas with excellent solar resources and significant load growth. SCE expects to place some projects in these highly-sensitive SCAQMD zones both to provide GHG-free renewable energy and to gain valuable understanding of intermittent distributed generation impact on the system.

Solar PV systems typically require little maintenance and have long life times (20-25 years for panels, up to 20 years for inverters). SCE proposes the Solar PV Program as a utility-owned distributed generation project to be developed beginning with start-up in 2008[26] to help meet the Governor's rooftop solar goals without the need to add transmission.

F. The Solar PV Program Will Provide Valuable Information To The State

The Solar PV Program will provide valuable information to SCE and to the State. SCE, as a regulated public utility, is willing to share publicly the results of its experience with solar PV. Specifically, SCE will share information about: (1) how solar PV systems of 1 to 2 MW interact with SCE's distribution system; (2) forecasting and scheduling of solar PV generating facilities of 1 to 2 MW

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[25] D.07-12-052, *mimeo,* p. 2.

[26] Concurrently with the filing of this application, SCE is filing an Advice Letter requesting establishment of a memorandum account for start-up costs. SCE estimates start-up capital costs to be $25 million in 2008. The memorandum account will allow SCE to recover start-up costs to support immediate start-up of work on this program.

disbursed throughout SCE's inland service territory; (3) information about training and availability of the skilled workforce for installation and maintenance of these facilities; and (4) information about potential streamlining and revision of tariff applications, local and state codes, and best installation practices for 1 to 2 MW solar PV projects.

1. Information On Interaction Of Solar PV With The Distribution System

With regard to the interaction of these Solar PV generating facilities with SCE's distribution system, SCE will study the effect of: (1) dependability and availability of generation from the Solar PV Program; (2) the effects of increased amounts of solar PV on distribution circuits; (3) the reaction of Solar PV Program generating facilities to grid disturbances; and (4) the reaction of the grid to Solar PV Program generating facilities' disturbances. To date, solar PV systems installed in SCE's service territory have been smaller than those proposed as part of this project and have not amounted to large fractions of circuit saturation. Such systems have also been net metered because they are customer-owned facilities. This means the actual total solar PV generation is unknown. SCE only knows the net output of these facilities after meeting their customer-owner's load. The large scale deployment of PV under utility ownership will permit SCE to evaluate the efficiency and economics of the generation technologies with precision that is not currently available due to net metering arrangements.

The Solar PV Program generating facilities would export all of their power to the distribution system. The intermittent nature of solar PV systems, especially during partially cloudy conditions, can cause rapid swings in solar facility output. SCE will measure the impact of the solar PV system on distribution circuit voltages, amperage, and other power quality attributes, and, if necessary, will determine the most cost-effective remedial measures.

SCE intends to study how the intermittency of 1 to 2 MW solar PV installations will affect its system. Solar PV power output typically peaks two to four hours before peak system operating

conditions when circuits are most heavily loaded.[27] That being said, solar PV total energy has been highest on summer days when circuits are typically highly loaded.

Solar PV systems are currently set to trip off during high or low voltage excursions. As solar PV becomes more prevalent, SCE may want to keep these systems on-line over a greater voltage range to improve reliable power flow from the solar PV. SCE will gather valuable data to determine new solar PV circuit interruption settings.

2. Information And Experience Forecasting Solar PV Output

The Solar PV Program will give SCE experience in forecasting the output from solar PV generating facilities. SCE will develop advanced weather monitoring and generation prediction models to estimate the energy that will be generated under various weather conditions. SCE will share these models and the underlying data with others.

3. Information On Workforce Training

Because SCE intends to work with a few specialized installation vendors, these vendors can begin to train a skilled workforce on the construction of these types of facilities. In addition, SCE will become acquainted with maintenance practices required for these types of facilities and will begin training a skilled workforce to provide those services.

4. Information On Streamlining Of Tariff Applications For Solar PV

Currently, these larger solar PV installations require individual FERC interconnection tariff applications. With multiple sites being installed, SCE will gain experience on streamlining the FERC interconnection process as well as optimizing system impact studies. For example, answers to questions like, "Is it practical and preferred for small solar PV projects (1 to 20 MW) to be aggregated in the SGIP and CAISO generation queues?" may be answered.

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[27] See Figure II-1 above.

III.

PROGRAM DESCRIPTION

A. Size of Program

SCE proposes to install the Solar PV Program's initial size of up to 250 MW over five years at a base case capital cost of $875 million. SCE's reasonableness threshold for the Solar PV Program is $962.5 million which is the base case estimate plus a 10% contingency. In years one through five, SCE plans to install solar PV systems at a rate of about 50 MW per year. SCE's strategic intent is not to overheat the market for solar PV panels, equipment and installation resources. Based on performance, SCE may seek Commission approval to increase the overall size of the Solar PV Program to a total of 500 MW, likely through a combination of installing more MW per year and lengthening the program. SCE proposes a limited amount of Year 0 activity to facilitate swift start-up of the full-scale program. This activity would setup key systems, processes, personnel, roof leases and system installation for the purposes of program testing and revision only.

The Solar PV Program installation goals are all based on the PV industry convention of using dc output. Unless otherwise specified, the energy output in this filing follows the common convention within the PV industry, which is to refer to output as PV panel dc output. Additionally, the Commission should use the installed dc output in reasonableness reviews because installation occurs in dc panels. Based on sample calculations using the California Energy Commission's ac MW conversion, the conversion factor of 0.90 will be used to convert from MW dc to MW alternating current (ac) (i.e., multiply MW dc by 0.90 to obtain CEC-ac Rating).

B. Length of Program

SCE proposes its Solar PV Program to continue for five years. To facilitate a swift start-up after Commission approval, SCE is concurrently filing an advice letter requesting authority to establish a memorandum account. The memorandum account will record start-up costs for preliminary studies, evaluations, and installation of up to 5 MW of solar PV facilities in 2008. SCE estimates Solar PV Program capital expenditures will total $25 million in 2008. If the Commission has not approved this

application by December 2008, SCE will record its 2009 start-up costs in the memorandum account as well. Specifically, the memorandum account will record costs of the following:

- Leases with building owners
- Identification of the buildings best suited to gain the most knowledge for the preliminary study
- Determination of which technologies to install to gain the most knowledge for the preliminary study
- Engineering plans
- Equipment purchase orders
- Building permits
- Installation procedures/training

Upon approval of the program (requested by year-end 2008), SCE's proposed schedule calls for the initial 250 MW of Solar PV generation to be installed within five years. On average, SCE will install 50 MW per year.

Table III-3 below shows the expected schedule for the Solar PV Program.

Table III-3
Estimated Solar PV Program Schedule

Date	Event
March 2008	SCE files application with the CPUC
April 2008	Commission approves establishment of memorandum account for Solar PV Program start-up activities
April 2008	SCE conducts all necessary preliminary studies and evaluations and installs up to 5 MW of 1 to 2 MW solar PV systems at an estimated capital cost of $25 million in 2008 until larger program approval (requested in December, 2008). If full program approval is not received until 2009, the capital costs may exceed $25 million.
After Solar PV Program approval	SCE will install up to 250 MW of solar PV generation, averaging 50 MW per year

C. Description of Facilities

1. Type of Facilities

Two solar PV module technologies are currently employed by the solar PV industry: (1) crystalline modules, and (2) thin film modules. These two different technologies can be further categorized depending on the materials used to create the cells that convert sunlight into electricity. SCE may install both technologies to compare their effectiveness and costs.

a) Crystalline Technology

Crystalline modules dominate the solar PV market, accounting for approximately 90% of the installed MWs. These large, rectangular modules are seen on most PV installations. The modules are rigid with a surrounding aluminum frame and a protective glass surface.

All crystalline modules use silicon as the primary material for converting sunlight into electricity.[28] When these materials absorb sunlight, the solar energy knocks electrons loose from

[28] Silicon is the same material used by companies such as Intel, AMD and others to manufacture computer chips.

their atoms, allowing the electrons to flow through the material to produce electricity. This process converts light (photons) to electricity (voltage).

Figure III-2
Typical Crystalline Solar PV Module
175 watts measuring approximately
64"x 32" x 1.75" and weighing 33 pounds

Crystalline modules fall into two primary types: (1) multicrystalline; and (2) monocrystalline. These terms refer to the type of silicon formulation of the individual *cells* that generate the current inside the module. Simply stated, raw silicon is used to create ingots which are then sliced into thin wafers. These low wattage wafers, or cells, are then wired to each other to increase their output. Figure III-2 shows seventy-two black cells wired to each other and sandwiched between a sheet of tempered glass on top and a protective backing on the rear. The tempered glass makes for a robust product that is impervious to all but the most extreme weather conditions (baseball size hail might damage a module) and normal hazards. An aluminum frame surrounds the glass for mounting purposes.

Monocrystalline modules are generally more efficient and more expensive to manufacture than multicrystalline modules. This increases the cost of the module. Just like light bulbs,

crystalline modules are available in various wattages. The size of the module will vary depending on its wattage and other factors.[29] Crystalline modules require a mounting structure, typically referred to a *rack*, to support it on the roof. Generally, crystalline module warranties are 20-25 years, depending on the manufacturer.

b) Thin Film Technology

Thin film modules fall into two broad categories: amorphous and rigid. Unlike crystalline modules, amorphous thin film use significantly less silicon than crystalline modules and a few other thin film technologies use no silicon to generate electricity.

Figure III-3 below shows that a flexible amorphous thin film modules are flexible panels that can be applied to curved as well as straight surfaces. These modules are manufactured with multiple layers of semiconductor materials that are only a few micrometers thick. These layers are attached to a flexible metal backing called substrate, through a spray-on process. The outer nonconductive layer looks like rubber. Flexible amorphous modules are usually attached to a metal roof known as a *standing seam roof.* An adhesive is applied to the rear surface of the module at the factory. Installers remove the plastic protection to expose the adhesive. The module is then rolled onto the standing seam roof. As these modules have no frame, unless the roof is a standing seam roof, amorphous modules may not be practical for rooftop applications.

[29] Solar modules are rated using both national and international standards. This means a 100 W rated module will produce 100 W but its actual physical dimensions and mounting arrangement vary by manufacturer. Solar modules are not a standard physical size, such as a 4 foot by 8 foot piece of plywood.

Figure III-3
Typical Amorphous Thin Film Module
Measuring 18 feet long by 15.5" wide
and Weighing_17 lbs.

Rigid thin film modules generally utilize different materials than amorphous and crystalline modules. Technologies include cadmium telluride (CdTe) and Copper Indium Gallium Selenide (CIGS). As with flexible thin film modules, a rigid thin film module has multiple layers of semiconductor materials. These layers are attached to a rigid substrate using the same spray-on process as an amorphous module. A tempered glass top protects the assembly. Pricing for these modules is significantly lower than any other commercially available PV module, but they have a lower efficiency than crystalline modules. Consequently, they are usually marketed towards large scale ground-mount systems for the utility market sector or are installed on very large rooftops where space is not a factor. Like crystalline modules, rigid thin film modules require a rack to support them. Generally, warranties on thin film modules are 25 years. Figure III-4 below shows a rigid thin film module.

Figure III-4
Typical Rigid Thin Film PV Module
Measuring 4 feet long by 2 feet wide
and Weighing 26.5 lbs.

SCE expects to see a new generation of thin film modules in the coming years based on a new generation of materials that is not currently commercially available. The markets these modules will serve (residential, commercial, utility) are not known.

c) Technology Comparison

There are tradeoffs when comparing crystalline and thin film technologies. Crystalline technology modules generate more power on a W per square foot basis than non-crystalline technologies. Although the numbers vary slightly from manufacturer to manufacturer (and from product to product within each manufacturer's offering), a crystalline module will generate approximately 12.3 W/sq ft. In contrast, at less than 6 W/sq ft., flexible amorphous modules have about half the efficiency of crystalline modules. Rigid thin film modules generate approximately 9.5 W/sq ft. Currently, thin film modules are less expensive than crystalline modules. Thin film modules require extra materials and labor to install as more modules are required to achieve the same system wattage as a system using

crystalline modules. If roof space is not an issue, thin film modules might be the preferred technology for a solar PV system. In addition to the lower module cost, thin film modules perform better than crystalline modules in low light, or diffuse lighting, conditions. So, they will generate more power on cloudy days. They also generate power earlier in the morning and later into dusk. All module technologies "derate" in hot weather, meaning as they get hotter, they become less and less efficient. Thin film modules derate less than crystalline modules. Therefore, thin film technology might be the preferred technology in certain southern California locations.

d) Inverters and Balance of System

All solar PV modules, regardless of technology, generate dc power. SCE must convert this dc power to ac power to use in its distribution system. Inverters perform this conversion. Figure III-5 depicts a 500 kW ac inverter. The inverter can be configured with custom software to be remotely controlled. This would allow SCE to change the system output based on circuit loads or weather conditions. Inverters are rated in ac. Inverters are available in various sizes from a few small kilowatts (kW) ac for residential solar PV systems to 500kW ac for large systems. Manufacturers are currently designing inverters above 1 MW ac.

Figure III-5 shows a 500kW ac inverter and transformer.

Figure III-5
500kW ac Inverter and Transformer
Inverter measuring 7.6"x9.6'x3'6" (HxWxD) transform measuring 5'x4'x4' (HxWxD) and weighing combined approximately 9,800 pounds.

Inverter ***Transformer***

Solar PV systems also include conduit, wire, dc and ac disconnects (safety devices to turn off or isolate parts of the system), and combiner boxes. Modules are wired together in series (imagine multiple batteries in a flashlight) into "strings." These strings can vary in number from 6 to 18, depending on a number of factors (module type and lowest temperature one might see at the project location). These larger string quantities enter boxes located throughout the array and are then "combined" into a smaller number of parallel wires that are then wired into the inverter. All of the items in a solar PV sytem other than the modules are commonly called Balance of System (BOS) components.

e) PV Module Mounting Systems

Except for flexible, amorphous thin film modules, all solar PV systems require some type of attachment method. This product is typically called a *rack.* There are two main categories of racks: penetrating and non-penetrating. Non-penetrating racks are further defined as ballasted (requiring some weight to be added to the rack besides the modules) or non-ballasted (primarily relying

on the weight of the rack and modules themselves to hold the array in place). SCE does not plan to use penetrating racks in the Solar PV Program to minimize the probability of roof leaks.

Non-penetrating racks are precisely as the name implies. The rack sits on top of the roof. Ballasted systems require the use of weighted material such as cinder blocks or pavers to keep the array in place. These systems add a significant amount of weight to the array. The total weight of ballasted systems, including modules, can reach 8 pounds per square foot and most commercial roofs cannot support this weight. Non-ballasted systems rely on the weight of the array itself to keep them in place and typically weigh 3-5 pounds per square foot, including modules. For an installation subject to high wind conditions an adhesive material (Sika or M1), ballasting material, or a combination of both, might be required at the edges of the array. The manufacturer of the rack will typically specify what is required to assure the PV array will meet local building department codes for anticipated winds. A local structural engineer will then confirm these calculations.

Figure III-6 is a non-penetrating rack adhered to the roof with M1 adhesive. The modules on the left side are in their normal operating position. The module is about 1 foot above the roof at its highest point. The right photo shows 1 row tilted to allow access to the wiring underneath the modules and to the roof for maintenance. Thin film modules are usually not tilted. They are installed parallel to the roof and are less than 1 foot off the roof surface.

Figure III-6
1.2 MW Non-Penetrating Solar PV
System on Commercial Rooftop in Sacramento, CA

f) Building Integrated PV

The state of California is committed to promoting the use of Building Integrated Photovoltaic (BIPV) products on new buildings. As evidence of this, the aforementioned CEC PV R&D Plan states that the goals of their program include: ". . . identifying synergies between PV and energy efficiency by 2008 and achieving widespread penetration of BIPV products by 2017. These milestones will provide improved performance, ease of use, and economics of PV systems, thereby supporting CSI and SB 1." There are an extremely limited number of BIPV installations worldwide to date. SCE's program will test and encourage this type of installation. Developers may only focus on existing roofs as they are the cheapest installation.

A key benefit SCE can bring to this effort is coordination between the various elements of Demand-Side Management (DSM). SCE's New Construction Services (NCS) group is an in-house team of technical specialists in energy efficiency (EE) and sustainable design. NCS is responsible for delivering SCE's commercial new construction EE offerings to building owners, developers, architects, and engineers. One way NCS delivers these offerings is by building and maintaining relationships with specific developers. As a result, NCS can review and analyze all of a developer's planned projects for EE opportunities. SCE is working to expand NCS's offerings to new construction

projects to include on-site renewable energy incentives, electric transportation (particularly for fork-lift operation), and demand response capabilities.

Large customers, also have assigned account managers through our Business Customer Division (BCD), who are the single point-of-contact through all of their dealings with SCE. This ensures continuity of service, and refers any eligible EE projects to the appropriate program. Similarly, because of ongoing relationships with owners and design teams in particular, many projects referred to NCS cover improvements to current building stock. For program purposes, SCE divides gut remodels (considered new construction) from simple equipment swap-outs (considered retrofits). NCS refers any such projects to either Standard Performance Contracting (SPC) or Express Efficiency, depending upon the scope of the retrofit.

However, one challenge to working with large customers that operate as landlords (often through property management firms), leasing commercial real estate to tenants, is that the tenants pay the utility bills. SCE may not have identified the landlord through our BCD. If SCE was not involved in the construction of the facility, it may not have a relationship with the actual owner. As large customers that operate as landlords buy and sell properties, often with the express intention of retaining lucrative tenants, this becomes an additional challenge.

A key part of the effort to integrate DSM services is the emphasis upon the CPUC's loading order: invest in cost-effective EE (and demand response) first and only then meet the remaining load with renewables. SCE would also work through CSI group to make sure that any projects (including warehouses) pursuing PV had been contacted by their BCD account manager to discuss opportunities for DSM.

SCE can leverage this delivery model to great effect with the large customers that lease commercial real estate to tenants in our service territory. This will enable SCE to pursue additional improvements in EE in commercial buildings even if they are not suitable candidates for the Solar PV program.

2. Size of Facilities

Rooftop arrays vary in size depending on the PV module technology being used and whether it is a tilted or flat array. Crystalline modules typically tilt toward the south and thin film modules are usually flat mounted.

Tilted arrays require more roof space than flat arrays because there must be adequate space between each row of modules to keep them from shading the adjacent row. An array with a 5 degree tilt will require less space between rows than an array with a 20 degree tilt. A flat array only requires enough space between module rows to allow a technician to walk between them for maintenance. Generally, a 1 MW array employing crystalline modules will require 125,000 square feet of roof space. A 1 MW rigid thin film array will require 175,000 square feet of roof space. A 1 MW flexible amorphous thin film array will require 230,000 square feet of roof space. These numbers include space required for conduit, combiner boxes, and other BOS components associated with the array. The required roofspace could increase depending on other roof protrusions they could potentially shade the modules or prevent a module from being installed. A protrusion is defined as anything on the roof (i.e., air handlers, skylights, vents, or drains). Protrusions could substantially impact the required roof space to prevent module shading from the object. For example, an air handler that is 8 feet tall should have 16 feet of clearance to the closest module that could be shaded.

None of the module technologies are visible from street level. The combination of building height, minimal height of the array above the roof, and setback of the array from the edge of the roof (usually 3 feet) all contribute to it being hidden. Also, for safety reasons, many buildings have a parapet around the building that also serves as a blind for existing equipment such as air handlers.

Figure III-7 is a street level photograph of the solar PV system on the rooftop of the Long Beach Convention and Entertainment Center in Long Beach, CA. There is a 1 to 2 foot parapet surrounding the rooftop, and the array is set back from the roof edge by around 3 feet.

Figure III-7
Photograph of the Long Beach Convention and Entertainment Center illustrating the solar PV array is not visible from street level

Inverters vary in size depending on the model. A single 1MW inverter dimensions are double that of a 500kW inverter. Typical 1 MW transformer dimensions are 9'x8'x5' (HxWxD) for an air-cooled transformer. Oil-cooled transformers are smaller than air-cooled transformers.

Inverters are typically located inside the building in an electrical room. If such a room is not available, the inverter(s) can be located outdoors next to the building. It is desirable to locate it as close to the array as possible to minimize power loss due to long wire runs. Inverters are designed to be installed outdoors. So, no additional enclosed building is required to house them. It is preferable to locate inverters in areas with less sun or inside a shade structure in hot, sunny locations. This is because heat can degrade inverter performance.

3. Location and Configuration of Facilities

SCE's Solar PV Program will study the appropriate locations of the 1 to 2 MW solar PV installations. SCE will develop methods to determine the optimal location for the PV installations. SCE will consider: (1) quality of the local solar resource (estimate of expected PV generation based on

factors such as expected cloud/fog cover, haze and smog, ambient temperature, and geographic latitude) and other meteorological data, (2) roof capacity and other building attributes, and (3) local circuit concerns.

To determine the quality of the local solar resource, SCE will rely on the National Renewable Energy Lab (NREL) database that provides information down to 10 km grids. By choosing the best combinations of available roof-site location and local solar resource, SCE will optimize the output of the solar PV installations. SCE will also consider other meteorological data. For example, high wind areas may preclude certain solar PV panel attachment methods. Crystalline solar PV panel performance degrades under high temperature conditions. So, more moderate temperature zones may be more desirable than very hot desert regions for this technology. To assess the impact of various solar quality areas, SCE may also install solar PV in poorer solar areas, such as those affected by the regional "June Gloom" (severely overcast). SCE will, then, quantify the effects on solar PV output of location, the resulting impact on the grid, and the implications for sizing back-up power (at the substation) or required demand response (from customers on the affected circuit).

In terms of roof capacity and other building attributes, SCE will take into account the following variables:

(1) Roof Capacity – Depending on the module technology being employed and roof protrusions, each roof must have available up to 250,000 square feet of available space per 1 MW installation.

(2) Roof Loading - Roofs must handle the additional weight loading which can vary based on technology as well as the individual vendor's panel weight. In general, the roofs must hold an additional 3 to 5 lbs. per square foot.

(3) Shading and orientation –Roofs should have little to no shading and be oriented to achieve the desired solar PV panel output profile. Normally, this means a south-facing exposure, as this orientation maximizes overall output of the installation. SCE may also consider a west-facing exposure to increase late afternoon sun which is more coincident with system load.

(4) Building Electrical Loads – SCE will identify buildings that have the size and structural strength to accommodate 1 to 2 MW and would not be typical candidates for net energy metering. For example, a large warehouse roof with little on-site load.

(5) Ground space requirements – SCE will need 100 to 200 square feet of ground space (indoors or outdoors) to install the inverters and transformers as these are typically too heavy to install on a roof.

(6) Contractual and other concerns – The conditions for leasing the roof and roof access are of key concern. The ease of local permitting may also play a role in determining the location of the facilities.

4. Interconnection Facilities

Figure III-8 illustrates typical interconnection facilities for a rooftop solar PV project. The figure shows a single line diagram for an existing distribution circuit (Box A), existing customer service (Box B), and the proposed new service for solar PV projects (Box C).[30] The simplest interconnection utilizes an existing transformer located on the customer's property shown as a 12kV/277-480 Transformer in Figure III-8. Interconnection facilities include a new line from the existing transformer shown in Box B, to a new utility panel housing a meter and a disconnect switch shown in Box C. The utility panel also functions as an interconnection point to connect the output wire lead from the solar PV generation facilities into a utility electrical panel. SCE's preferred interconnection includes a visible disconnect switch so utility workers can readily identify where to manually isolate solar PV generation from the rest of the electrical grid. SCE is also pursuing the ability to isolate the solar PV generator from the grid using remote signal to the inverter.

Figure III-9 shows a simplified interconnection utilizing an existing transformer. Some customer locations may not possess such a transformer. Therefore SCE anticipates adding a transformer as part of the interconnection facilities. Figure III-9 shows a more complex interconnection because it includes a new transformer and pad mounted switch. Looking at Box C in Figure III-9, the

[30] A single line diagram shows one phase of a three phase electrical system. An actual installation would include three wires where one is shown, but not three transformers or switches as those devices accept three phases of electricity.

interconnection facilities consist of a wire from the existing transformer in Box B to a new pad mounted electrical switch (shown as PME-11) in Box C. From there, a cable connects the pad mounted switch to the new transformer. The remaining facilities are similar to those shown in Figure III-8; namely a wire from the transformer to a new utility panel housing a meter and a visible switch. This box connects the wire lead from the solar roof top generation facilities into a utility electrical box.

Combined, Figures III-8 and III-9 illustrate the range of interconnection options SCE expects to use in the Solar PV Program. These figures illustrate simple and conceptual interconnections. Actual interconnections may vary on a case-by-case basis.

Figure III-8
Proposed System Single Line
Simplified Interconnection

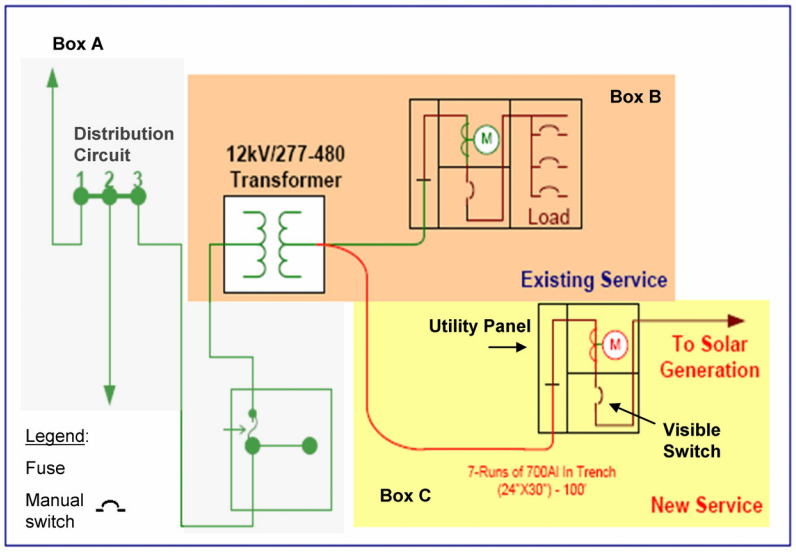
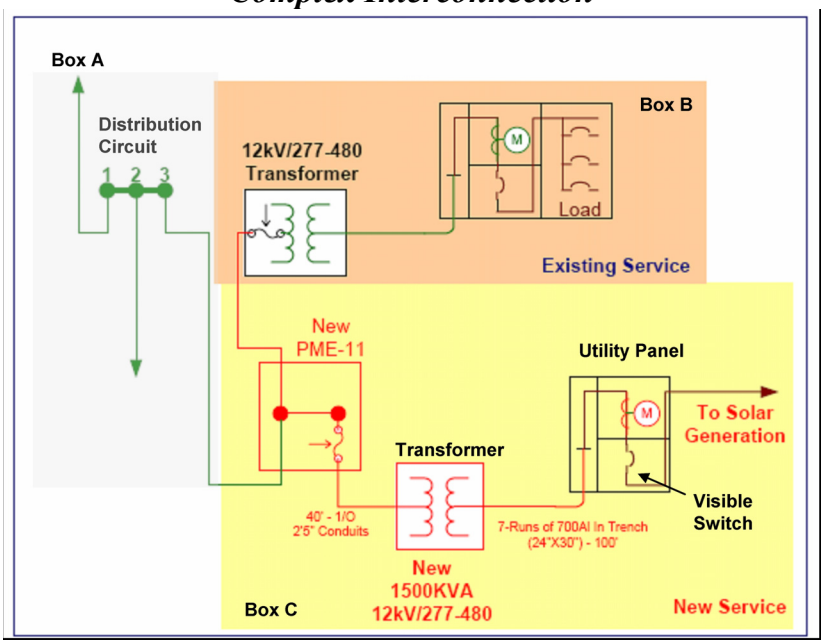


Figure III-9
Proposed System Single Line
Complex Interconnection



5. Data Acquisition System (DAS)

The DAS will gather operating data at each site. This data can provide valuable information regarding the energy quantity and quality output of the PV systems tested. The DAS will

include weather sensory equipment that will enable SCE: (1) to compare the actual output with projections from computer generated models, and (2) to evaluate the impact of weather conditions experienced on the quantity and quality of power output.

Any generating station connecting to the CAISO Grid must enter into a Meter Service Agreement (MSA) with the CAISO. The CAISO requires certain operational data be supplied to them on an ongoing basis as part of interconnecting generation to the electric grid. The DAS systems will collect and send this data to the CAISO real time.

All generation connected to the CAISO grid must forecast and schedule power into the CAISO system on an hourly basis. Currently an intermittent technology such as solar PV would participate in the CAISO's PIRP. However, the PIRP currently only schedules wind resources. SCE will work cooperatively with the CAISO and others to formulate the requirements for solar PV to join the PIRP. For a generation facility not in PIRP, the generation forecast is due nearly 3 hours ahead of the actual generation period. This is a challenging task for solar PV generation. As a part of this project, SCE will identify predictive weather methodologies, such as cloud movement to attempt to forecast output of these PV systems for the CAISO 3 hours ahead until implementation of the PIRP requirements for solar PV.

SCE will install all components between the inverter and the point of delivery to the grid. The DAS components are forecast to cost approximately $200,000, for each 1 to 2 MW solar facility, as follows:

- Meter $10,000
- Communications $45,000
- Data collection $40,000
- Weather station $55,000
- Auxiliaries $50,000

6. Leasing Rooftop Space For Facilities

The success of the Solar PV Program is in large part dependent upon securing appropriate lease agreements with building owners/developers. As noted above, SCE intends in the first phase to

install up to 250 MW of solar PV on commercial building rooftops at various locations within SCE's service territory. The proposed 1 to 2 MW installation per location will require up to about 250,000 sq. ft. of rooftop space. For this Solar PV Program, SCE anticipates that it will look to a limited number of building owners/developers to provide appropriate location inventory in order to more efficiently select appropriate locations and limit the number of simultaneous lease negotiations.

Upon the selection of appropriate locations for the PV Facilities, SCE intends to enter into negotiations with the owner/developers of those sites in order to secure a mutually agreeable rooftop lease. Because the large-scale installation of utility-owned rooftop PV systems is a relatively novel concept, the Solar PV Program will allow SCE to gain valuable experience regarding certain rooftop lease business deal points such as optimal lease terms, appropriate rental rate structures, reasonable site access requirements. In every instance, however, SCE will negotiate to secure appropriate and reasonable clauses to ensure appropriate allocation of the rights and obligations of SCE and the respective owner and protection of ratepayer interests.

SCE may also opt to locate a few 1 to 2 MW installations on utility-owned roofs as well.

IV.

PROGRAM COST ESTIMATE

A. Capital

1. Generating Facilities Cost

Table IV-4 below provides estimated costs for a typical 1 MW project. Due to the volatile price of petroleum and copper, wire distributors will only quote pricing for 30 days. Table IV-4 projects average shipping costs which can vary depending on the actual locations of the solar PV facility.

Table IV-4
Estimated Hardware Cost for 1 MW Solar PV Project
(2008$)

Hardware	Cost
PV System (Module, Rack, Balance of System)	$2,540,275
Data Acquisition System (DAS)	$ 200,000
Interconnection Equipment	$ 150,000
TOTAL HARDWARE COST	$2,890,275

2. Installation Cost

Table IV-5 provides estimated installation costs for a typical 1 MW project. On-site installation costs can vary substantially based on labor rates in effect at the time of the installation.

Table IV-5
Estimated Installation Cost for 1 MW Solar PV Project
(2008$)

Labor Activity	Cost
Site Selection	$ 3,000
Engineering	$ 35,000
Permits	$ 10,000
Installation and Commissioning	$461,725
Project Management	$100,000
Total	$530,200
TOTAL LABOR COST	$609,725
$/W	$ 0.61

Assuming computer-based or hard copies of drawings do not exist, a survey will be made of the rooftop before the array layout can begin. This is in addition to an initial site walk of the building. Once the engineering drawings are completed, the roof must be marked for the array layout.

Delivery of modules, inverters, rack hardware, and Balance of System (BOS) components includes the process of lifting the equipment to the roof with a crane and locating it throughout the roof to distribute the weight. The delivery schedule can be modified to minimize disruption to the customer. This could either be a compressed schedule of trucks making deliveries to a staging area next to the crane while personnel lift product to the roof (more disruption over a shorter duration), or activities can be spread out to minimize traffic (less disruption over a longer duration).

Once all materials have been placed on the roof, installation of the array can begin. During this phase of the installation, impact to the daily operations of the building activities are minimal and are primarily associated with letting installation personnel onto the roof and closing roof access at the end of the day. The building lessee's security procedures could increase the length of the installation

period. Vehicles on site are primarily those associated with workers commuting to the site. Additional disruption is possible due to trench work required to tie-in the inverter to the SCE circuit. Commissioning is the process of turning on the system, testing and notation taking, and troubleshooting any problems.

Total on-site installation time is approximately 30-45 days for a 1 MW project. However, the time for completion of the first project after regulatory approval is about 4-6 months due to lead times to order the modules and inverters.

3. Interconnection Costs

Interconnection costs range from about $70,000 for simple installation to $150,000 for the more complex installation (in 2008$). The main difference in costs between the two types of installations is the addition of a new distribution transformer and pad mounted switch. These estimated costs assume a reasonable distance of new distribution cable (100 feet), which if longer or shorter could increase or decrease costs respectively. Cable costs assume underground installation. These cost figures illustrate simple and conceptual interconnections. Actual interconnection costs may vary on a case-by-case basis.

The proposed Solar PV Program would apply for interconnection service pursuant to SCE's Wholesale Distribution Access Tariff (WDAT) for each site using the Small Generator Interconnection Process (SGIP), just as any other non-SCE generation project is required to apply for such service. SCE expects the cost of each interconnection to range from $1,500 to $9,000 depending if the interconnection is applicable for the WDAT's fast track process or normal track process.

4. Total Program Capital Costs

SCE proposes to install up to 250 MW of PV generation within 5 years at a base case cost of $875 million. The overall base case cost of the Solar PV Program averages $3.50/W, including $2.89/W of material costs and $0.61/W of labor costs. SCE's proposed reasonableness threshold is $962.5 million which is the base case amount plus a reasonable 10% contingency. The reasonableness threshold cost of the Solar PV Program averages $3.85/W. Table IV-6 summarizes the capital cost of the Solar PV Program per year.

Table IV-6
Summary of Capital Costs of Solar PV Program
(2008$)

Year	Capital (Million$)	MW Installed	Estimated Time Frame
0	$25	5	April '08 to Dec '08
1	$174	50	2009
2	$174	50	2010
3	$174	50	2011
4	$174	50	2012
5	$154	45	2013
Total	$875	250	

Though the Solar PV Program estimates a base case total installed cost of $3.50 per watt, the average cost of installation will vary from year to year. The costs incurred during the start-up phase of the program (listed as year "0") are estimated to be $25 million for up to 5 MW of installed PV generation, which produces an average installed cost of $5/W (2008$) for that year. The increased average cost is higher in the first year because of:

- Contact Development / Procurement – SCE will work with PV manufacturers and installers to develop agreements which is labor intensive.
- Site Evaluation and Selection – SCE Distribution Field Engineering will locate and evaluate the best locations to install PV to maximize grid benefits.
- Data Monitoring – SCE will install additional data monitoring equipment on the initial installations to better evaluate performance.
- Process Optimization and Optimization – SCE will use the start-up phase to gain knowledge and develop optimal process for interconnection and installation.

Beyond Year "0", SCE estimates the cost per installation to remain constant at $3.48/W (2008$). Once SCE standardizes the processes and contracts in the start-up phase, the individual

installation costs will remain stable in constant dollars. Individual project cost will vary due to locational issues (permitting, ease of installation), but the average costs should remain fairly stable. SCE assumes 50 MW of solar PV installed per year for years 1-4 resulting in a annual capital expenditure of $174 million. SCE assumes 45 MW of solar PV installed in year 5 at an average cost of $3.42/W ($2008). The total capital expenditures for year 5 are forecast to be $154 million.

B. Operation & Maintenance Cost

1. Roof Lease Payments

The leasing of roof space for PV panel installations is a novel concept. No real market reference pricing currently exists. The Solar PV Program differs from most large-scale rooftop PV deployments. This program will be for large roof buildings that would not otherwise be typical candidates for net energy metering. The closest business model is the rooftop cell phone tower installations. But even these are not representative, as they occupy a much smaller area of the roof.

SCE is engaged in discussions with numerous Real Estate Investment Trusts which own large numbers of commercial buildings, to determine mutually equitable arrangement for leasing roof-space. SCE is exploring multiple options to establish a market price, such as leases based on a square foot basis and those based on a percentage of gross power output value. Other issues, such as liability minimization, roof access, lease term, etc., are also being examined to determine acceptable contracting terms.

As this is a new opportunity for the large rooftop owners, it is difficult to estimate the expected leasing rates. SCE realizes that the maximum price paid for these roof leases must be kept to a small percentage (equal to or less than 10%) of the value of the electricity being produced.

SCE has identified numerous potential leasing partners whose portfolios contain several times the amount of roof space needed for even the 500 MW program. SCE is confident that the leasing issues can be adequately addressed to the satisfaction of both parties and that, ultimately, ample cost-effective roof leases can be arranged.

2. Maintenance Cost

Preventative maintenance costs are typically low for solar PV systems. Generally, maintenance consists of washing the modules once or twice each year to facilitate maximum energy production. The frequency could vary depending on specific site conditions. Regularly monitoring the system output through the DAS will provide the necessary information to determine when cleaning is required. A visual inspection of the array once a year is also usually recommended and can be performed at the same time as a routine cleaning. Inverters do not typically require routine maintenance other than to make sure the air filters are clean. If the inverters are installed indoors, a yearly visual inspection should suffice.

Table IV-7 contains an estimate of annual O&M costs, not including the roof lease for a 1 MW solar PV project of $35,000 (2008 $). The Solar PV Program would add up to 50 such projects each year, increasing O&M by $2.626 million per year.

Table IV-7
Estimated Yearly O&M Costs for a 1 MW Solar PV Project
(2008$)

Labor Activity	Cost per Year	Frequency
Array Cleaning	$ 10,000	2x per year
Array Inspection	$ 5,000	1x per year
DAS Monitoring	$ 20,000	Monthly
TOTAL O&M COST PER YEAR	$ 35,000	

3. Staffing

The Solar PV Program will require a staff of 11 Full Time Equivalent (FTE) employees. If the Commission authorizes SCE's Solar PV Program, SCE's current staffing level is insufficient to provide adequate oversight and project development capability.

Table IV-8 summarizes the costs associated with the required additional employees.

Table IV-8
Solar PV Program Management Labor Forecast Increase For New Employees
(2008$)

Line No.	Incremental Staffing:	# Positions	Total Labor Increase
1	Manager - Project/Product 2	8	$ 1,029,768
2	Manager 3	1	$ 163,296
3	Technical Specialist 3	2	$ 199,710
3	Total Increase in Labor	11	$ 1,392,774

These employees will provide the project management and program contract oversight necessary for the Solar PV Program. The employees would include senior management, technical specialists, and senior project managers including:

- **Vendor Relationship Management** – Responsible for managing rooftop, panel and supplier relationships. Will have the contact management function. Ongoing primary point of control for all vendors, contracts, and internal SCE interactions. Two Manager-Project/Product 2 positions for the six years of the program.
- **Site Management** – Responsible for site selection, coordination, and interconnect management. Primary point of contact during "pre-installation" phase. Works to assure prompt interconnect activity and permitting coordination. Two Manager-Project/Product 2 positions for the six years of the program.
- **Installation Management** – Responsible for managing the installation process through Engineer, Procure, Construct (EPC) Vendor, or multiple contractors. Executes site management's plan. Two Manager-Project/Product 2 positions for the six years of the program.
- **Business Management** – Responsible for planning, strategy, reporting and management of department and project budgets, staff, regulatory reporting and

other activities. Two Manager-Project/Product 2 positions for the six years of the program.

- **Operations** – Responsible for project maintenance and monitoring. One Manager 3 and two Technical Specialist 3 positions beginning in year 2 of the program. In addition, the Manager 3 will have management responsibility for the program staff.

Table IV-9 below summarizes the proposed staffing costs each year. The dates listed assume approval of the memorandum account in April, 2008.

Table IV-9
Forecast Summary of Staffing Costs of Solar PV Program

Year	Labor (2008$)	Estimated Time Frame
0	$737,514	April '08 to Dec '08
1	$1,290,419	2009
2	$1,392,774	2011
3	$1,392,774	2012
4	$1,392,774	2013
5	$1,392,774	2014

V.

RATEMAKING

A. Introduction

This chapter presents SCE's cost recovery proposal for the Solar PV Program. SCE is requesting recovery of the revenue requirement associated with the costs associated with Solar PV Program activities described in the previous chapters. SCE expects to incur approximately $53.8 million (2008$) in O&M and $875.0 million (2007$) in direct capital expenditures over the 2008 through 2014 program period, and requests that the Commission find reasonable up to $962.5 million (2008$) in direct capital expenditures during the 2008 through 2014 program period.

B. Forecast of SCE's Solar PV Program Revenue Requirements

Table V-10 below, contains the estimated annual revenue requirements during the 2008 through 2014 period.[31]

[31] The revenue requirement shown for 2008 will be recovered from customers in 2009 along with the estimated 2009 revenue requirement.

Table V-10
Summary of Solar PV Program Estimated Revenue Requirements
(O&M and Capital Costs)
Thousands of Dollars

Line No.	Item	2008 1/	2009	2010	2011	2012	2013	2014
1.	**Operating Revenues**	**3,497**	**28,148**	**66,809**	**102,374**	**135,238**	**164,573**	**169,670**
2.	**Operating Expenses:**							
3.	O&M Expense	1,000	4,294	7,311	10,401	13,659	16,809	17,319
4.	A&G – Benefits	298	536	596	614	632	651	671
5.	Uncollectible Expense	8	63	150	230	304	370	382
6.	Franchise Requirements	32	251	597	914	1,208	1,470	1,515
7.	Depreciation	547	6,734	17,044	27,566	38,316	48,750	53,562
8.	Taxes Other Than Income	0	125	1,285	3,211	4,899	6,427	7,711
9.	Taxes Based On Income	726	5,138	12,347	17,670	21,616	24,715	23,292
10.	Total Operating Expenses	2,612	17,142	39,331	60,605	80,635	99,192	104,452
11.	**Net Operating Revenue**	**886**	**11,006**	**27,478**	**41,769**	**54,603**	**65,381**	**65,218**
12.	**Rate Base (Average)**	9,095	112,882	281,823	428,401	560,026	670,579	668,906
13.	**Rate Of Return**	9.75%	9.75%	9.75%	9.75%	9.75%	9.75%	9.75%
1/ The 2008 annual revenue requirement has been prorated assuming an effective date of April 1, 2008.								

Beginning in 2009, SCE requests to include in generation rate levels, and recover from bundled service customers, the forecast Solar PV Program revenue requirement each year until this revenue requirement is included in SCE's GRC revenue requirement.[32] As discussed in more detail below, differences between the Solar PV Program-related generation retail revenue and the actual recorded Solar PV Program revenue requirement based on recorded costs (i.e., over- or under-collection) will be

[32] It should be noted that by paying for these costs, SCE's bundled service customers would see a reduction in their energy procurement costs reflected in SCE's Energy Resource Recovery Account (ERRRA) revenue requirement because SCE would not need to procure the equivalent amount of energy from other sources.

recorded in the SPVPBA. SCE will also include the estimated above market cost of the annual revenue requirement in the calculation of the vintaged Cost Responsibility Surcharges (CRS) applicable to Direct Access, Departing Load and Community Choice Aggregation customers each year.[33]

If as discussed in Chapter I, the Solar PV program is successful, SCE may seek additional authority to expand the program to 500 MW. In the request to expand the program, SCE will include its proposal to continue to use the SPVPBA during the expansion period.

1. Capital Expenditures/Additions

For purposes of estimating the annual revenue requirements contained in Table V-10 above, SCE used the direct capital expenditures estimated to be $875 million in constant 2008$ shown in Table IV-6. Table V-11 shows the estimated direct capital expenditures for each calendar year, plus escalation based on the index discussed in Section D below, plus an adder to estimate overheads such as, Allowance for Funds Used During Construction (AFUDC), capitalized pensions and benefits, payroll and property taxes.[34] The total estimated nominal expenditures in the amount of $1,028.0 million are included in forecast plant-in-service (i.e., rate base) as of the date the plant investment is estimated to go in service.

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[33] Currently, the Commission authorizes the CRS rates in SCE's annual ERRA Forecast Proceedings.

[34] SCE will not include capitalized A&G on recorded capital expenditures included in the SPVPBA.

Table V-11
Summary of Solar PV Program Calendar Year Capital Expenditures
$millions

Col. A	Col. B	Col. C	Col. D	Col. E	Col. F
Year	**MW**	**Direct Expenditures ($millions)**	**Escalation ($millions)**	**Overhead Adder ($millions)**	**Total Expenditures ($millions)**
2008	5	25.0	-	2.5	27.5
2009	50	174.0	3.7	17.8	195.5
2010	50	174.0	7.4	18.1	199.5
2011	50	174.0	11.4	18.5	203.9
2012	50	174.0	15.6	19.0	208.6
2013	45	154.0	21.4	17.5	192.9
2014	-	-	-	-	-
Total	250	875.0	59.5	93.5	1,028.0

2. Depreciation Expense

Table V-10 estimates the total depreciation expense during the 2008 through 2014 period to be $192.5 million. For purposes of estimating depreciation expense, the capital costs are divided into five categories: (1) PV Modules and Balance of System Components; (2) PV Rack; (3) General; and (4) Distribution. Each of these categories are explained below along with the estimated depreciable lives, net salvage requirements, and resulting depreciation rates.

a) Generating Facilities Plant

(i) PV Modules and Balance of System Components

These assets include the PV modules that convert sunlight into electricity, the inverter to convert dc to ac to use on SCE's distribution system, and the balance of system components not in other categories. Chapter III, Program Description, Section C, Description of Facilities describes these assets in detail.

The warranties of the solar PV modules range from 20-25 years depending on the manufacturer. Most warranties are limited and simply cover loss in power due to defects in workmanship or materials. When developing a depreciable life for plant assets, however, there are

many other forces of retirement to consider in addition to defects in workmanship or material. These retirement forces for rooftop PV may include (but are not limited to): weather (wind, electrical, and rain storms), fire, theft, vandalism, terminating lease contracts, roof failure, and obsolescence. Considering all forces of asset retirement the average depreciable life of the PV modules could average 15-20 years (i.e., some may retire earlier or later). At this time, SCE proposes using an average service life of 20 years.

The estimated decommissioning cost for the solar PV system is approximately $75,000/MW in 2008 dollars. The decommissioning costs are expected to be incurred 20 years after the date of installation of the PV Production assets. So, SCE projected the costs at the expected retirement date. Depreciation accrual for decommissioning begins upon installation of the underlying assets. Table V-10 shows the future decommissioning estimates and the estimated future annual deprecation expense for the assets installed in each respective year.

Table V-12
Summary of Future Decommissioning Expenses (included in Depr. Expense)
thousands of dollars

Year Installed	MW	Year Retired	Decommissioning $75 / MW	Escalation Factor 1/	Decommissioning (retirement year$)	Annual Depreciation 2/
2008	5	2028	$375	1.6395	$615	$31
2009	50	2029	$3,750	1.6323	$6,121	$306
2010	50	2030	$3,750	1.6263	$6,099	$305
2011	50	2031	$3,750	1.6208	$6,078	$304
2012	50	2032	$3,750	1.6198	$6,074	$304
2013	45	2033	$3,375	1.6220	$5,474	$274

1 / Escalation factor is based on Global Insight Chain-Weighted GDP between year installed and year retired

2/ Assets are estimated to be installed mid-year, so the first year of estimated depreciation will be half the annual amount.

(ii) PV Rack

The PV rack is the support structure for the PV modules, made primarily of aluminum and miscellaneous hardware. Chapter III, Program Description, Section C, Description of Facilities explains the rack in detail. As a support structure, the estimated depreciable life of the PV rack is 30 years.

b) General Plant

The general plant in the Solar PV Program is the data acquisition system (DAS). The DAS will include data collection, metering, communication, and weather sensoring equipment. This equipment is primarily modern, digital electronic computer and microprocessor-equipment and is similar to SCE's existing Supervisory Control and Data Acquisition (SCADA) equipment. SCE's current authorized depreciation lives for this type of SCADA equipment ranges from 7 to 15 years.[35] For purposes of estimating depreciation in this filing, SCE used 10 years. The net salvage requirement for this equipment is estimated at zero percent.

c) Distribution Plant

The distribution plant is the equipment required to connect the solar PV generation to the distribution grid. The plant may include overhead conductor, underground conduit and conductor, disconnect switches, distribution line transformers, services, and other distribution equipment. SCE determined the estimated depreciation for these assets using composite depreciation rates based on SCE's 2006 General Rate Case (GRC) Decision[36] authorized depreciation rates for year 2008 cost estimates, and its proposed 2009 GRC[37] depreciation rates for years 2009 through 2014. The current authorized depreciation rates are based on an average service life of 30 to 55 years and net salvage requirements ranging from 0 to -100 percent.

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[35] D. 06-05-016. SCE's proposed depreciation lives in its 2009 GRC (A. 07-11-011) are the same.

[36] D. 06-05-016

[37] A. 07-11-011

3. Rate of Return

As authorized in D.06-05-039, SCE calculated the rate of return on rate base using SCE's current authorized rate of return of 8.75%, plus 1%, since this new plant will be utility-owned renewable generation.

4. O&M Expense

Table V-11 shows the estimated O&M expenses by year included in the estimated revenue requirements shown in Table V-10. Column C of Table V-13, shows the total estimated O&M expenses in the amount of $53.83 million in constant $2008 as supported in the previous chapters.[38] Column D includes the annual estimated incremental staffing expenses in the amount of $8.98 million as supported in Chapter IV.[39] Column E includes an estimate of the benefits associated with the incremental staffing in the amount of $3.63 million. Column F includes estimated escalation associated with the amounts included in Columns C through E based on escalation rates supported in SCE's 2009 GRC Application (A.07-11-011). Therefore, as shown in Column G, the total estimated nominal O&M expenses included in the estimated 2008 through 2014 annual revenue requirements is $74.79 million.

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[38] For example, the estimated maintenance and roof lease O&M for 2008 is calculated by multiplying 5 MW by $52,520/MW. For purposes of calculating and annual revenue requirement for 2014, SCE has included a full year of estimated O&M expenses.

[39] Table IV-9

Table V-13
Summary of Solar PV Program Calendar Year Estimated O&M Expenditures
$millions

Col. A	Col. B	Col. C	Col. D	Col. E	Col. F	Col. G
		Non-Labor	**Labor Related**			
Year	**Cumulative Installed MW**	**$2008 Constant**	**Labor $2008 Constant**	**Benefits $2008 Constant**	**Escalation**	**Total Nominal**
2008	5	0.26	0.74	0.30	-	1.30
2009	55	2.89	1.29	0.52	0.13	4.83
2010	105	5.51	1.39	0.56	0.44	7.91
2011	155	8.14	1.39	0.56	0.92	11.01
2012	205	10.77	1.39	0.56	1.58	14.29
2013	250	13.13	1.39	0.56	2.38	17.46
2014	250	13.13	1.39	0.56	2.90	17.99
Total		53.83	8.98	3.63	8.35	74.79

5. Income Taxes

SCE estimates income taxes by following the rules and methods traditionally adopted in the Company's GRC. Specifically, in computing tax depreciation, SCE uses the five year MACRS (Modified Accelerated Cost Recovery System) tax life for federal purposes and a five year life, straight-line method, for computing state tax depreciation. For Federal tax purposes, SCE includes 50% Bonus Depreciation for all 2008 capital additions that meet prescribed requirements. Deferred taxes are estimated as required by the Internal Revenue Code. SCE computes tax basis by removing any recorded Allowance for Funds Used During Construction (AFUDC) and replacing it with tax capitalized interest following the rules of Internal Revenue Code Section 263A. SCE also computes a tax deduction for the benefits of Internal Revenue Code Section 199. SCE computes tax expense and the corresponding

deferred taxes using the applicable Federal corporate tax rate of 35% for each year and an apportioned state corporate tax rate, as applicable.[40]

C. Description of Solar PV Program Balancing Account (SPVPBA)

SCE requests that the Commission authorize SCE to establish the SPVPBA to record the difference between: 1) the actual incremental O&M and capital-related revenue requirement associated with the Solar PV Program and; 2) the recorded Solar PV Program-related generation retail revenue. The SPVPBA will ensure that no more and no less than the reasonably incurred actual revenue requirement associated with the Solar PV Program is ultimately recovered from customers. The incremental O&M costs that will be recorded in the SPVPBA will include such things as the cost of cleaning, inspecting and monitoring the solar PV equipment, lease costs, insurance, incremental labor associated with the staffing requirements to manage the project, and travel expenses.[41] SCE proposes to also record the revenue requirement (i.e. depreciation,[42] property, payroll and income taxes, and return calculated at the authorized rate of return on rate base) associated with actual Solar PV Program capital additions.[43] Consistent with D.06-05-039, SCE will calculate the rate of return on rate base using SCE's current authorized rate of return of 8.75%, plus 1%, since this new plant will be utility-owned renewable generation.[44]

SCE will continue to record entries in the SPVPBA until both the O&M and capital-related revenue requirements are included in SCE's GRC revenue requirement, which is expected to be January 1, 2015, or sooner.

---

[40] Congress is currently proposing legislation that could produce tax credits for solar projects. If enacted and if this project meets the requirements and qualifications of any enacted legislation, SCE will record any solar tax credit benefits in the SPVPBA taking into account the normalization requirements

[41] SCE will also record applicable benefits associated with any incremental labor that is recorded in the SPVPBA.

[42] The depreciation expense recorded to the SPVPBA for these assets will reflect the current authorized depreciation rates for the respective general plant accounts and will be updated, as necessary, as a result of SCE's 2009 GRC decision and any subsequent General Rate Case decision regarding depreciation of the respective plant accounts.

[43] Capital additions include overheads such as AFUDC, capitalized property and payroll taxes, and pension and benefits added to direct expenditures of $875 million.

[44] The Commission in D.06-05-039 implemented the California Legislature's authorization for increased incentive for utility ownership of renewable generation.

On March 27, 2008, SCE filed an advice letter requesting Commission authority to establish the SPVPMA to record all incremental O&M expenses, invoiced costs for outside services (e.g., consultants and vendors), insurance, and any capital-related revenue requirement incurred as a result of SCE's Solar PV Program activities prior to Commission approval of SCE's ratemaking request in this instant application. The establishment of the SPVPMA is necessary to ensure that the Solar PV Program can proceed without delay and without precluding cost recovery at a future date. Similar to all Commission-approved memorandum accounts, the SPVPMA will protect against retroactive ratemaking concerns, but will not guarantee recovery in rates of any recorded costs prior to Commission review and approval. SCE plans to only use the interim ratemaking (i.e. the SPVPMA) while this application is pending in 2008 to record incremental O&M and capital-related revenue requirement associated with the first $25 million of direct capital expenditures. If the Commission does not act on this application in 2008, SCE will record incremental O&M and capital-related revenue requirement above $25 million in the SPVPMA until a final Commission decision is issued. Finally, upon approval of this application, SCE will transfer the balance recorded in the SPVPMA to the SPVPBA.

At the end of each year, SCE proposes to transfer the balance recorded in the SPVPBA, either over- or under-collected, to the generation sub-account of the Base Revenue Requirement Balancing Account (BRRBA). At the beginning of each year, SCE consolidates the December 31st balance recorded in the generation sub-account of the BRRBA in generation rate levels to be recovered from bundled service customers.

D. Proposed Reasonableness Review and Standard for Reasonableness Review

SCE proposes to include in its annual April ERRA Reasonableness proceedings, testimony supporting the reasonableness of the O&M costs recorded in the SPVPBA during the prior calendar year. SCE proposes that if SCE's direct capital expenditures in each calendar year of the program are less, on a $/W basis than the amount in Table V-14 below, then those capital expenditures will be deemed to be reasonable.

Table V-14
Reasonableness Review Threshold For Direct Solar PV Program Capital Costs (2008$)[45]

Expenditures Incurred During	$/W
2008	5.50
2009	3.83
2010	3.83
2011	3.83
2012	3.83
2013	3.76

The threshold levels contained in Table V-14 are reasonable because they represent SCE's base case estimate of Solar PV Program cost per Watt, as shown on Table IV-6, plus a reasonable 10% contingency.

1. Inflation Adjustment

Because direct capital expenditures will be recorded in nominal dollars during each year of the project, the $/W costs in Table V-14 will have to be adjusted for general price inflation between 2008 and later years. SCE proposes to accomplish this by multiplying the $/W costs in 2008 dollars by the ratio of the Gross Domestic Product Price Index (GDPPI) for the calendar year being reviewed to the Gross Domestic Product Price Index for 2008. Expressed as a formula where *RT* is the reasonableness threshold:

$$RT_t = RT_{\text{Table V-14}} \times \frac{GDPPI_t}{GDPPI_{2008}}$$

2. Reasonableness Review Procedure

In any year that SCE's direct capital expenditures, on a $/W basis, exceed the amounts set forth in Table V-14 above, as escalated, SCE will include, in its annual April ERRA Reasonableness

[45] These threshold amounts will be escalated to nominal year amounts for use in reasonableness review.

proceedings, testimony supporting the reasonableness of the capital expenditures during the previous calendar year. Even if no reasonableness testimony is required, SCE will include for Commission audit and review the O&M and capital revenue requirement recorded in the SPVPBA in its annual April ERRA Reasonableness proceeding.

Appendix A

Witness Qualifications

SOUTHERN CALIFORNIA EDISON COMPANY

QUALIFICATIONS AND PREPARED TESTIMONY

OF RICHARD FISHER

Q. Please state your name and business address for the record.

A. My name is Richard Fisher, and my business address is 2244 Walnut Grove Avenue, Rosemead, California 91770.

Q. Briefly describe your present responsibilities at the Southern California Edison Company.

A. I am the manager of the Rate Base and Depreciation group in the Capital Recovery Division, responsible for recorded depreciation, nuclear decommissioning, and portions of rate base.

Q. Briefly describe your educational and professional background.

A. I have a Bachelor of Science Degree in Business Administration, with an emphasis in Finance, Real Estate, and Law, from California State Polytechnic University, Pomona. I am currently completing course work towards a Masters degree in Business Administration at the University of Southern California and will be completed by June 2008. I am a member of the Society of Depreciation Professionals and have been qualified as a Certified Depreciation Professional.

Since my employment with Southern California Edison in 1999 I have been with the Capital Recovery Division of the Controllers Department. My responsibilities have included functions involving depreciation and nuclear decommissioning accounting, depreciation studies, and the development of forecasting models for plant additions, rate base, and depreciation expense in direct support of the Company's regulatory proceedings. I have previously testified before the California Public Utilities Commission.

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony in this proceeding is to sponsor those portions of Exhibit No. SCE-1, entitled *Solar Photovoltaic (PV) Program Testimony,* as identified in the Table of Contents thereto.

Q. Was this material prepared by you or under your supervision?

A. Yes, it was.

1 Q. Insofar as this material is factual in nature, do you believe it to be correct?

2 A. Yes, I do.

3 Q. Insofar as this material is in the nature of opinion or judgment, does it represent your best

4 judgment?

5 A. Yes, it does.

6 Q. Does this conclude your qualifications and prepared testimony?

7 A. Yes, it does.

SOUTHERN CALIFORNIA EDISON COMPANY
QUALIFICATIONS AND PREPARED TESTIMONY
OF PAUL T. HUNT, JR.

Q. Please state your name and business address for the record.

A. My name is Paul T. Hunt, Jr., and my business address is 2244 Walnut Grove Avenue, Rosemead, California 91770.

Q. Briefly describe your present responsibilities at the Southern California Edison Company.

A. I am the Manager of Regulatory Finance and Economics, supervising the Regulatory Finance Division of the Treasurer's Department. My present responsibility is to apply economic, financial, and statistical analysis to regulatory issues and for internal corporate purposes.

Q. Briefly describe your educational and professional background.

A. I received a Bachelor of Arts degree in Economics from Pomona College in 1975, a Master of Arts degree in Economics from Stanford University in 1976, and a Doctor of Philosophy degree from Stanford University in 1981. I joined the Southern California Edison Company as an Associate Economist in the Treasurer's Department in July 1980. I was promoted to Economist in 1982 and Senior Economist in 1984. In 1989, I transferred to the Regulatory Policy and Affairs Department as a Regulatory Economics Consultant. I returned to the Treasurer's Department in 1996 as a Senior Economist. In 1997, I was promoted to Project Manager. I was promoted to my present position in 2000.

I have testified before the California Public Utilities Commission and the Federal Energy Regulatory Commission.

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony in this proceeding is to sponsor the portions of Exhibit No. SCE-1, entitled *Solar Photovoltaic (PV) Program Testimony,* as identified in the Table of Contents thereto.

1 Q. Was this material prepared by you or under your supervision?

2 A. Yes, it was.

3 Q. Insofar as this material is factual in nature, do you believe it to be correct?

4 A. Yes, I do.

5 Q. Insofar as this material is in the nature of opinion or judgment, does it represent your best
6 judgment?

7 A. Yes, it does.

8 Q. Does this conclude your qualifications and prepared testimony?

9 A. Yes, it does.

SOUTHERN CALIFORNIA EDISON COMPANY
QUALIFICATIONS AND PREPARED TESTIMONY
OF DEBORAH J. KLUN

Q. Please state your name and business address for the record.

A. My name is Deborah J. Klun, and my business address is 2244 Walnut Grove Avenue, Rosemead, California 91770.

Q. Briefly describe your present responsibilities at the Southern California Edison Company.

A. I am a Director in the Tax Department. Since late April 2007, I have been responsible for all tax matters in CPUC and FERC rate filings made by the company.

Q. Briefly describe your educational and professional background.

A. I hold an undergraduate degree in Accounting from De Paul University, a Master's degree in Taxation from De Paul University and a Juris Doctorate degree from Northwestern University. I have passed the CPA exam (Illinois), and am licensed to practice law in Hawaii. I have been employed in the Edison Tax Department since 1988. I have held various positions in the tax department, having responsibility for Tax Research and Planning, IRS Audits and the Accounting for Income Tax function, as well as, tax rate regulation. Prior to joining Edison, I worked as Director of Federal Tax for another corporation, I practiced with a large law firm and worked for a big four CPA firm.

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony in this proceeding is to sponsor those portions of Exhibit No. SCE-1, entitled *Solar Photovoltaic (PV) Program Testimony,* as identified in the Table of Contents thereto.

Q. Was this material prepared by you or under your supervision?

A. Yes, it was.

Q. Insofar as this material is factual in nature, do you believe it to be correct?

A. Yes, I do.

Q. Insofar as this material is in the nature of opinion or judgment, does it represent your best judgment?

A. Yes, it does.

1 Q. Does this conclude your qualifications and prepared testimony?

2 A. Yes, it does.

SOUTHERN CALIFORNIA EDISON COMPANY
QUALIFICATIONS AND PREPARED TESTIMONY
OF MARK E. NELSON

Q. Please state your name and business address for the record.

A. My name is Mark E. Nelson, and my business address is 8631 Rush Street, Rosemead, California 91770.

Q. Briefly describe your present responsibilities at the Southern California Edison Company.

A. I am the Director of Generation Planning and Strategy in the Generation Business Unit. My present responsibility includes the broad support of generation initiatives and regulatory efforts at SCE, and management of the Project Development Division.

Q. Briefly describe your educational and professional background.

A. I earned a Bachelor of Science degree in Economics from Iowa State University with emphasis work in Chemical Engineering and Systems. I earned a Master of Science degree in Econometrics from Iowa State University with thesis work in electricity demand analysis. I first joined the Southern California Edison Company as a Planning Engineer in 1991 and held various management positions through 1996, including Manager of Real Time Pricing and Customer Software Systems. In 1996 I joined Edison Source and held a number of management positions including Director of Retail Energy Operations until my departure in 1999 following the cessation of energy marketing activities. From 1999-2003, I served as Managing Consultant of Commerce Venture Group LLC, with primary responsibility for energy sector consulting and analysis. I rejoined Southern California Edison in 2003 as Integrated Planning Manager and was subsequently promoted to Manager of Strategic Projects in the Resource Planning & Strategy Department prior to promotion to my current position.

Prior to joining Southern California Edison, I served as a Consultant for Midwest Solar, Inc., a leading national supplier of large scale solar thermal systems, with responsibility for economic and engineering analysis from 1980-83. From 1983-88, I held management and analysis positions with subsidiaries of MidAmerican Energy, with responsibility for generation and

transmission projects, economic analysis, regulatory affairs and customer services. From 1988-91, I served as Vice President of Analysis for DATASSIST, where I was responsible for economic and statistical analysis of electric and gas utility projects.

I am the author of a number of energy and business books and articles, including: An Econometric Study of Residential Electricity Demand (ISBN 1-56471-005-X), Fundamentals of Business Process Analysis (1-56471-009-2), and "Understanding Natural Gas Demand for Electric Utilities."

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony in this proceeding is to sponsor the portions of Exhibit No. SCE-1 entitled *Solar Photovoltaic (PV) Program Testimony*, as identified in the Table of Contents thereto.

Q. Was this material prepared by you or under your supervision?

A. Yes, it was.

Q. Insofar as this material is factual in nature, do you believe it to be correct?

A. Yes, I do.

Q. Insofar as this material is in the nature of opinion or judgment, does it represent your best judgment?

A. Yes, it does.

Q. Does this conclude your qualifications and prepared testimony?

A. Yes, it does.

SOUTHERN CALIFORNIA EDISON COMPANY
QUALIFICATIONS AND PREPARED TESTIMONY
OF RUDY PEREZ

Q.1 Please state your name and business address for the record.

A.1 My name is Rodolfo "Rudy" Perez and my business address is Southern California Edison Company, 8631 Rush Street, Rosemead, California 91770.

Q.2 Briefly describe your present responsibilities at the Southern California Edison Company.

A.2 I am the current Project Manager for the development of the Solar Photovoltaic Program (SPVP) within the Generation Business Unit Planning and Strategy Group at the Southern California Edison Company.

Q.3 Briefly describe your educational and professional background.

A.3 I hold bachelor degrees in Chemical Engineering and Economics from the University of Notre Dame (Indiana) as well as a Masters in Business Administration from California State University – Long Beach. I also hold a California Professional Engineer's License in Mechanical Engineering. I have been an SCE employee for over 25 years holding various engineering and management positions within Generation, Transmission & Distribution and the Renewable and Alternative Power Organizations.

Q.4 What is the purpose of your testimony in this proceeding?

A.4 The purpose of my testimony in this proceeding is to sponsor the portions of Exhibit No. SCE-1, entitled *Solar Photovoltaic (PV) Program Testimony,* as set forth in the Table of Contents thereto.

Q.5 Was this material prepared by you or under your supervision?

A.5 Yes, it was.

Q.6 Insofar as this material is factual in nature, do you believe it to be correct?

A.6 Yes, I do.

Q.7 Insofar as this material is in the nature of opinion or judgment, does it represent your best judgment?

A.7 Yes, it does.

Q.8 Does this conclude your qualifications and prepared testimony?

A.8 Yes, it does.

SOUTHERN CALIFORNIA EDISON COMPANY

QUALIFICATIONS AND PREPARED TESTIMONY

OF GENE E. RODRIGUES

Q. Please state your name and business address for the record.

A. My name is **Gene E. Rodrigues**, and my business address is 6042A N. Irwindale Avenue, Irwindale, CA 91702.

Q. Briefly describe your present responsibilities at the Southern California Edison Company (SCE).

A. I am presently the Director of Energy Efficiency for SCE. In that capacity, I have direct oversight of SCE's portfolio of energy efficiency programs, low income energy efficiency programs, the California Alternate Rates for Energy (CARE) program, the self generation incentives program, California Solar Initiative and the measurement & evaluation and regulatory support functions for these areas.

Q. Briefly describe your educational and professional background.

A. I received a Bachelor of Science degree in Education from Northern Arizona University in 1980 and a Juris Doctor degree from the University of California, Hastings College of Law in 1988. Before coming to SCE, I taught high school in Arizona and practiced law with a civil litigation firm in Los Angeles. In 1990, I joined SCE's regulatory law department, where I provided legal support for SCE's energy efficiency programs, among other things. Since moving to the business side of SCE, I have held various positions within the Customer Service Business Unit, managing energy efficiency policy, operations and regulatory functions. My current position is Director of Energy Efficiency. I have previously practiced law and testified before the Commission.

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony in this proceeding is to sponsor the portions of Exhibit No. SCE-1, entitled *Solar Photovoltaic (PV) Program Testimony,* as set forth in the Table of Contents thereto.

Q. Was this material prepared by you or under your supervision?

1 A. Yes, it was.
2 Q. Insofar as this material is factual in nature, do you believe it to be correct?

3 A. Yes, I do.
4 Q. Insofar as this material is in the nature of opinion or judgment, does it represent your best
5 judgment?

6 A. Yes, it does.
7 Q. Does this conclude your qualifications and prepared testimony?

8 A. Yes, it does.

9

SOUTHERN CALIFORNIA EDISON COMPANY
QUALIFICATIONS AND PREPARED TESTIMONY
OF DOUGLAS A. SNOW

Q. Please state your name and business address for the record.

A. My name is Douglas A. Snow, and my business address is 2244 Walnut Grove Avenue, Rosemead, California 91770.

Q. Briefly describe your present responsibilities at the Southern California Edison Company (SCE).

A. I am the Manager of Revenue Requirements in SCE's Regulatory Policy and Affairs (RP&A) Department. As such, I am responsible for overseeing the operation of various Balancing and Memorandum Accounts and the associated disposition of the balances in those accounts for ratemaking purposes.

Q. Briefly describe your educational and professional background.

A. I graduated from Texas A&M University in May of 1982 with a Bachelors of Science Degree in Industrial Engineering. In June of 1982, I went to work for Southwestern Public Service Company (SPS) in west Texas. While there, I attained a title of Supervisory Engineer and was responsible for revenue requirement calculations and rate design for both retail and resale customers. I filed testimony on behalf of SPS before the Texas Public Utility Commission and the Federal Energy Regulatory Commission. In November of 1993, I went to work for the Southern California Edison Company as a Financial Analyst in the FERC Pricing section in the RP&A Department. While working in the FERC section, I was responsible for the rate design for SCE's requirements sales for resale, Wheeling Access Charges, and wholesale Distribution Access Charges. In March 1998, I became a Supervisor in the Revenue Requirements division of RP&A, responsible for supervising a group of analysts that oversee the forecasting and recording entries associated with all CPUC regulatory mechanisms. In December 2001, I was promoted to the position of manager in the Revenue Requirements division of RP&A. In August 2006, I was promoted to my current position as Manager of Revenue Requirements. I have previously testified before the California Public Utilities Commission.

Q. What is the purpose of your testimony in this proceeding?

A. The purpose of my testimony in this proceeding is to sponsor portions of Exhibit No. SCE-1, entitled *Solar Photovoltaic (PV) Program Testimony,* as identified in the Table of Contents thereto.

Q. Was this material prepared by you or under your supervision?

A. Yes, it was.

Q. Insofar as this material is factual in nature, do you believe it to be correct?

A. Yes, I do.

Q. Insofar as this material is in the nature of opinion or judgment, does it represent your best judgment?

A. Yes, it does.

Q. Does this conclude your qualifications and prepared testimony?

A. Yes, it does.

1

SNL

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Wednesday, June 09, 2010 11:21 AM ET

SoCalEd taps Trina Solar to supply 45 MW of PV modules

By Taigh Khan

China-based Trina Solar Ltd. said June 9 that its Trina Solar (US) Inc. subsidiary signed an agreement with Southern California Edison Co. to supply 45 MW of photovoltaic modules.

The modules will be supplied at agreed prices with deliveries taking place between the second quarter of 2010 and the first quarter of 2011. Initial shipments commenced in May, the company said in a news release.

The modules are expected to be used in SoCalEd's solar PV program, the company said.

The California Public Utilities Commission authorized the Edison International subsidiary to cover up to 65 million square feet of unused Southern California commercial rooftops with 250 MW of the PV installation.

"This program is a milestone in utility-owned PV generation in the United States and Trina Solar is excited to play a significant part in supplying modules representing approximately 20 percent of the solar capacity needed for the program," Jifan Gao, chairman and CEO of Trina Solar, said in the release.

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Record Growth in Photovoltaic Capacity and Momentum Builds for Concentrating Solar Power

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James Russell | Jun 03, 2010

An estimated 7,300 megawatts (MW) of new solar photovoltaic (PV) power capacity was installed in 2009—20 percent more than was added in 2008.[1] With this record addition, global installed PV capacity surpassed 21,000 megawatts, producing enough power to satisfy the annual electricity use of about 5.5 million households.[2] In addition, 127 MW of solar thermal electric power plants came online in 2009, bringing the total operating capacity of such plants to 613 MW.[34] Solar energy harnessed by PV and thermal electric plants now meets about 1 percent of electricity demand in Germany and more than 2 percent of demand in Spain.

Europe continues to be the center of global PV demand, installing 5,280 MW in 2009, equal to 72 percent of the global total.[5] (See Figure 1.) Germany alone was responsible for more than half of global PV installation, with a total of 3,800 MW installed.[6] Much of this record capacity increase was completed only in December, as solar developers rushed to complete projects before Germany's feed-in tariff was reduced by 10 percent in January 2010.[7] Installations by the previous record holder, Spain, plummeted from 2,700 MW in 2008 to about 70 MW in 2009.[8] This decline came as no surprise, however, as Spanish policymakers sharply reduced the solar feed-in-tariff and introduced a new project approval process to control costs and project quality.[9]

Italy was the second largest market for PV, with 580 MW installed.[10] Japan took third place with 480 MW installed, spurred on by a new obligation for utilities to purchase surplus PV electricity.[11] The United States was the fourth largest market, with about 470 MW installed, and the Czech Republic was fifth, with 410 MW installed.[12]

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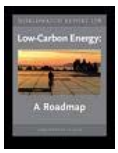

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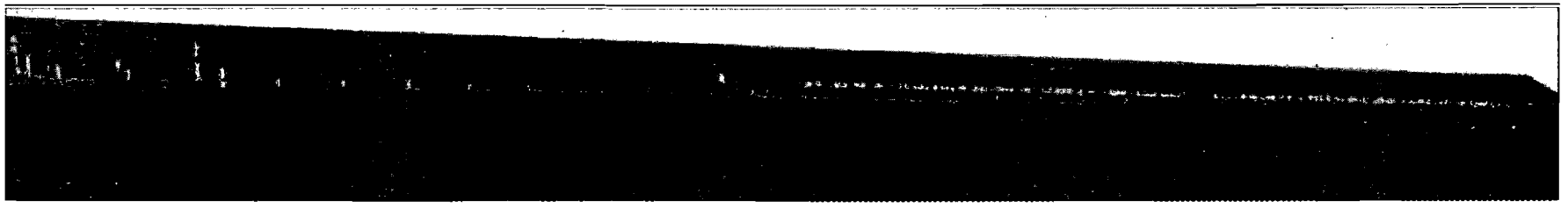
EuPD Research

I International Solar



PV Thin Film
Markets, Manufacturers, Margins

Daniela Schreiber

EuPD Research
San Francisco, November 2008

Exhibit 627

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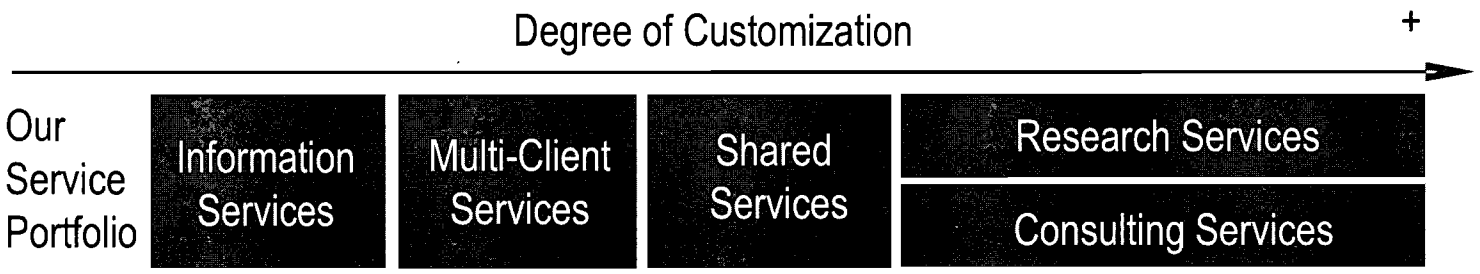
EXHIBIT 18

A. Introduction

PV Business Solutions: Profound Research and Consulting

- EuPD Research is a international market research and consulting company. Our services encompass all aspects of modern marketing solutions
- Covering everything from analysis to strategy development, implementation and controlling, we help our clients build their business



- More than 220 PV research & consulting projects successfully accomplished since 2001
- Our PV research analysts and consulting professionals represent more than 100 years of PV business experience

B. Markets

National Market Classification: Approach

Short-Term PV Market Attractiveness

Installation 2009e and 2010e	100%

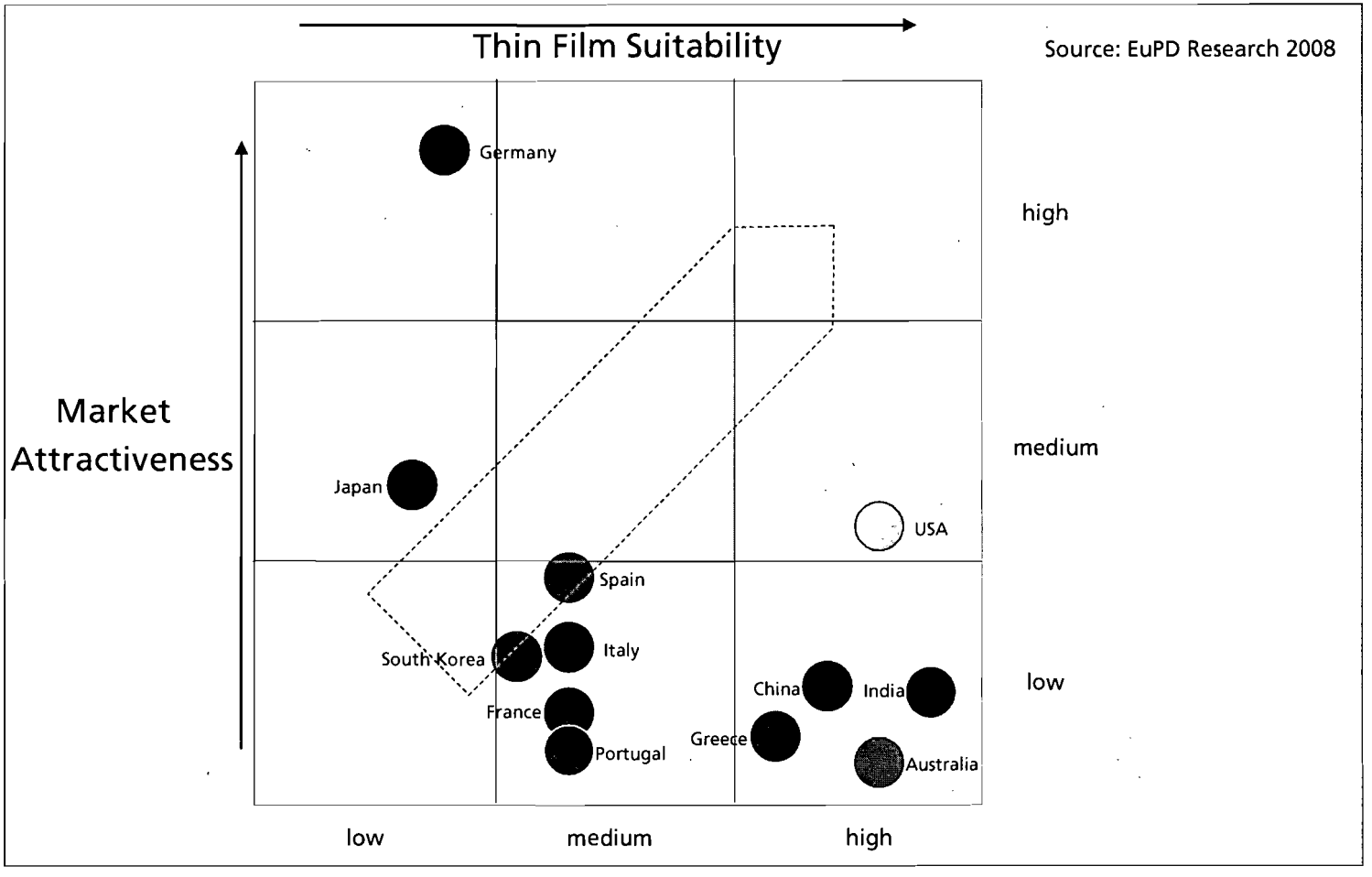
Long-Term PV Market Attractiveness

Gross National Product	10%
End Customer Energy Price	15%
Energy Consumption Growth (BAU) 2010 – 2015	25%
Solar Radiation	50%

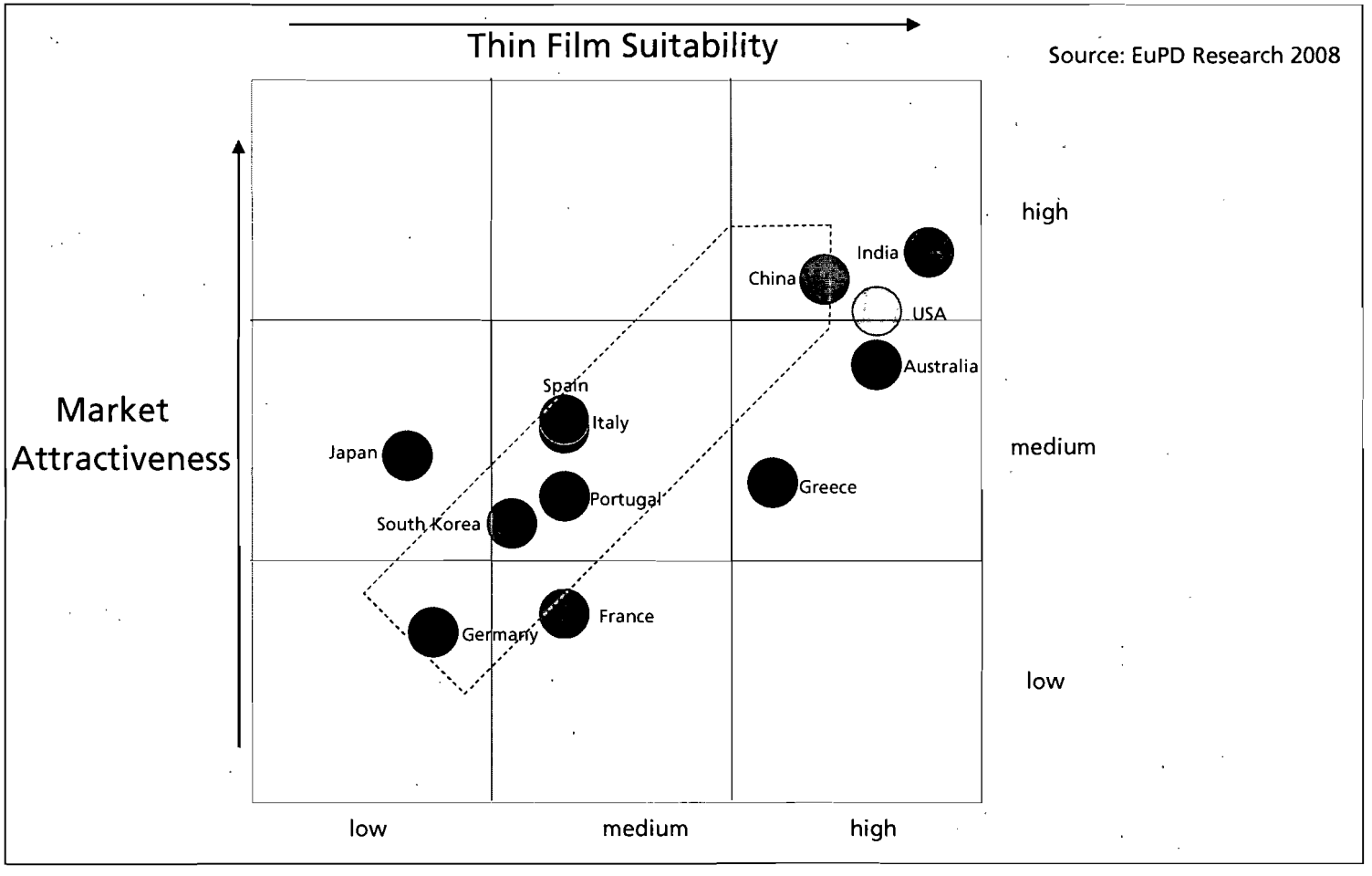
Thin Film Suitability of PV Market

Potential for Thin Film-Relevant Market Segments	50%
Thin Film Suitability of given Weather Conditions (temperature coefficient/fill factor under diffuse lightning)	50%

Short-Term Perspective of Country Markets



Long-Term Perspective of Country Markets



Markets: Conclusion

Why compete against crystalline in stagnating market conditions?

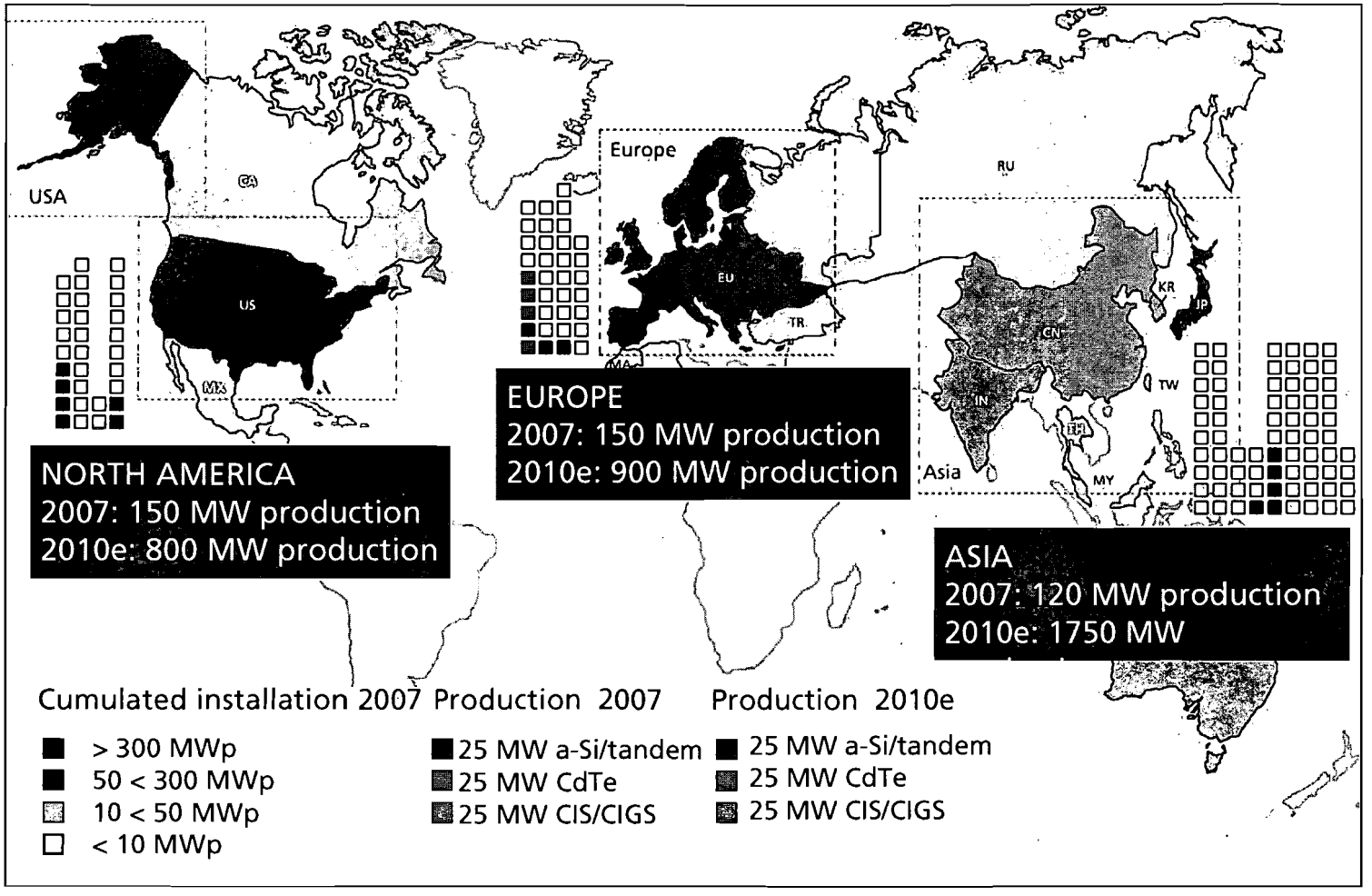
- Thin Film technologies are mainly suitable for large-scale open space installations and BIPV applications.
- However, the BAPV segment is expected to play an increasingly important role in the coming years in the European Top 4 markets Germany, Spain, Italy and France.
- In the European markets, the residential and commercial rooftop segments will gain more importance. Here, thin film modules are often a second-best solution.

Why not use thin film as a door-opener for new markets?

- In the countries with the highest theoretical PV potential like India, China, USA and Australia, the suitability for PV thin film applications is high.
- This has mainly to do with the hot weather conditions, under which the operational behavior of silicon and CdTe modules (temperature coefficient) may even outweigh the lower efficiency rate.

C. Manufacturers

Global PV Thin Film Production 2007 and 2010



Turnkey Providers and Their Customers

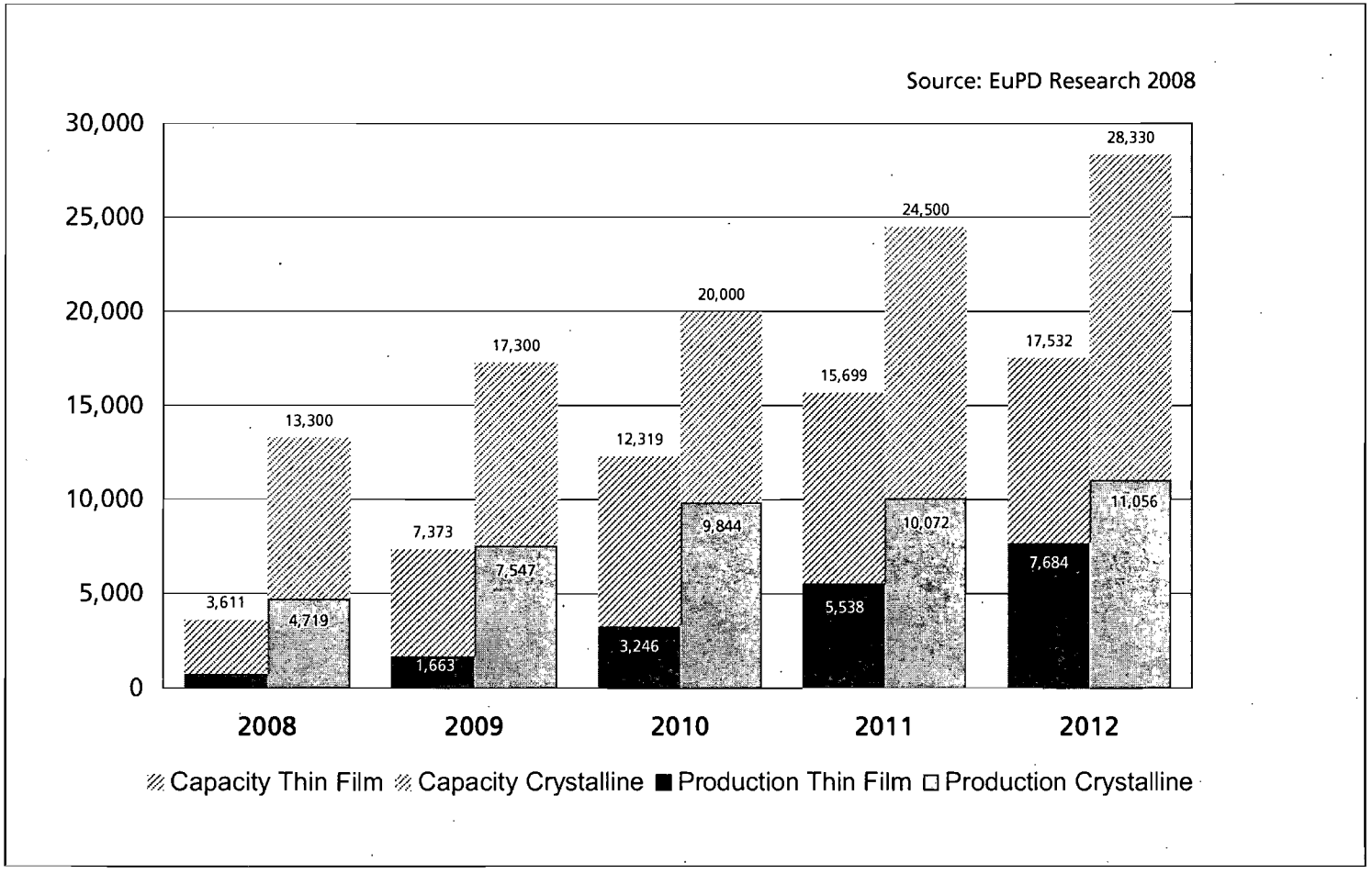
Best Solar, China
LDK
ENN Solar, China
Malibu, Germany
Schüco, E.On
Masdar PV, Abu Dhabi
Abu Dhabi Renewable Programme
Green Energy, Taiwan
Tatung Co.
Xinao, China
Moncada Energy Group, Italy
Moser Baer, India
T-Solar, Spain
Isolux Corsán
Applied Materials, USA
QS-Solar, Taiwan
Qiangsheng Co.
Sunfilm, Germany
Good Energies, Norsun
Signet Solar, Germany/USA
Sontor, Germany
Q-Cells
Solar Morph, China
Equation Co.

Further a-Si turnkey providers:
Anwell, Hong Kong
EPV, USA
Leybold Optics, Germany
Solar Thin Films, USA

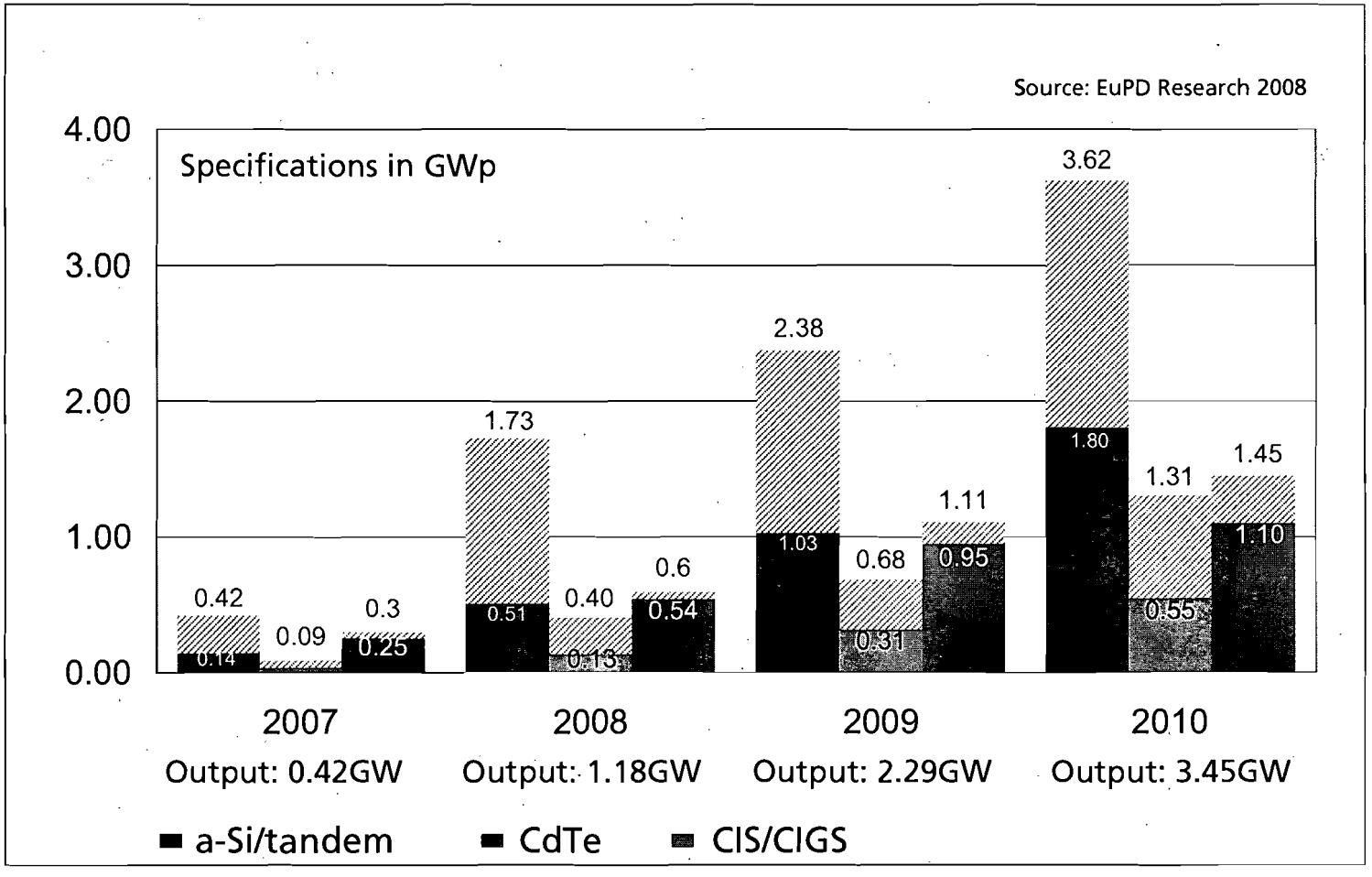
CIGS turnkey provider:
centrotherm, Germany

API, Germany
Saudi investors
Auria Solar, Taiwan
E-Ton, Lite-On
Sunways, China
CSG, Germany
Good Energies, Q-Cells
Sunwell
CMC Magnetics
Oerlikon, Switzerland
Chint Solar, China
China Solar Power, China
UMC, Unimicron
SCHOTT, Germany
Kenmos, Taiwan
Kenmos, NanoPV
Gadir Solar, Spain
ersol, Germany
Ulvac, Japan
Pramac, Italy
Inventux, Germany
Former Schüco staff
NexPower, Taiwan
Next Solar, Greece
Sunner Solar, Taiwan
Fortune Group
Nanowin, Taiwan

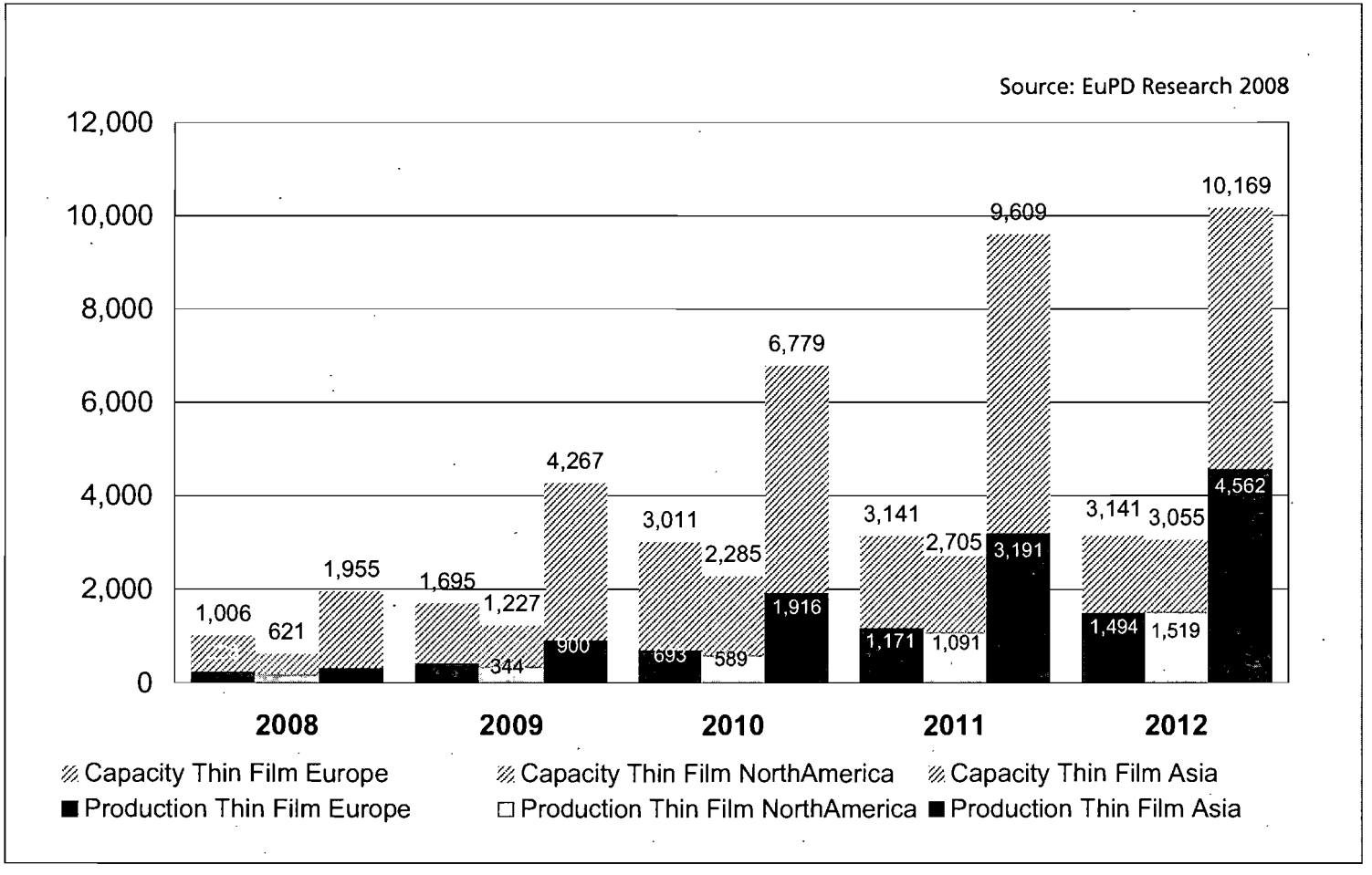
Thin Film vs. Crystalline 2007 – 2012



Capacity and Expected Production Output



PV Thin Film Capacity in Europe, America and Asia



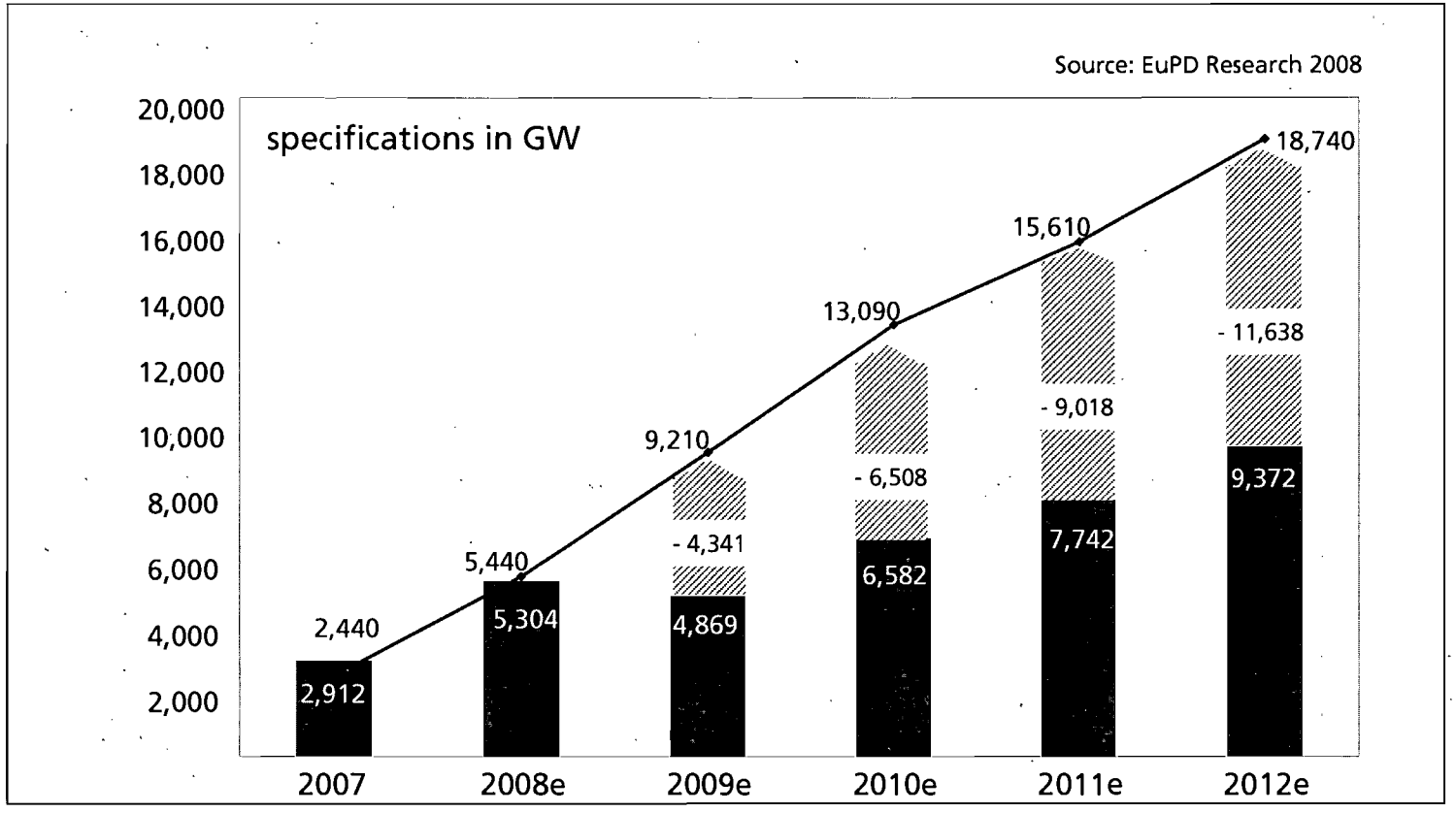
Thin Film Companies (State: 08/08)

R&D 19	Seed phase 23	Start-Up phase 25	Plant construction 25	Pilot production 15	Commercial production 9
Aisin Seiki	APL O	CIS Solar F	Ascent F	Avancis	First Solar
Dyesol	Arendi	DayStar F	Auria O	Calyxo	Honda
Flisom F	Bengbu	Formosun	AVA Solar	CSG O	Kaneka
Fujikura	Canon	Genesis	Best Solar A	EPV	Mitsubishi H.
G-24	Canrom	Heliogrid	China Solar	Global Solar F	SCHOTT O
Innovalight O	Gadir Solar O	Koncar	Flexcell F	Johanna	Uni-Solar F
Inter Phases	Golden Phot.	Lambda	Free Energy	Malibu A	Würth
Isetinc	Helianthos	Masdar PV A	Fuji Electric F	Nanosolar F	
Konarka F	Heliodomi	Miasole F	Green Energy A	Showa Shell	
Octilion O	ICP Solar	Nantong A	Heliovolt	Signet Solar A	
Orion Solar	Jiangsu	NextSolar O	Inventux O	Solibro	
Panasonic	JNL Solar	Odersun	Kenmos O	Sontor A	
Peccell F	OptiSolar	Polar PV F	Moser Baer A	Sulfurcell	
Photonic	Solarion F	Power Film F	Nanowin O	Sunfilm A	
Plextronics	Solar Techn.	PVFlex F	NexPower	Sunwell O	
Q1 Nano O	Solems	QS Solar A	NextSolar O	SHARP	
Solaris Solarmer O	Soltech	ShanShan	Pramac O	ersol O	
Solexant O	Solyndra	Sinonar	Prime Star		
Sony O	Stellaris	Solarion A	Scheuten		
	Stion	SoloPower	Solar Plus		
	Terra Solar	Sunner Solar	Sunways		
	Tianjin	Teksun	Sunwell O		
	Topray	Trony	Suntech		
		XinAO A	T-Solar A		
		Xunlight	XsunX		

Legend

Technologies	Suppliers	
a-Si / tandem	Applied	A
CdTe	Oerlikon	O
CIS	Ulvac	
Organic PV		
Nano PV	Flexible PV	F

The Gap: PV Supply and PV Demand



global PV demand
global PV production

Manufacturers: Conclusion

Some 140 companies have announced plans to produce PV thin film...

- Worldwide, some 140 companies have announced plans to start commercial production of PV thin film modules within the next five years.
- Most of the entrants are betting on silicon thin film technologies (a-Si, tandem and triple junction).
- Although American and Japanese companies are the current industry leaders, more and more competition will arise from German and South-East Asian manufacturers.

...but only five are already doing so.

- Currently, five companies are selling modules in quantities larger than ten MW, among them First Solar, Uni-Solar, Kaneka and Mitsubishi Heavy.
- Hence, the expansion and ramp-up plans should be assessed cautiously, especially with regard to the financial crisis. Many of the expected entrants will bail-out.
- The turnkey suppliers play an important role in the technology diffusion process.

Thank you very much for your attention!

Editorial

EuPD Research
Adenauerallee 134
D-53113 Bonn
Phone +49 (0) 228-971 43-0
Fax +49 (0) 228-971 43-11
welcome@eupd-research.com
www.eupd-research.com

Contact
Daniela Schreiber
Head of Research Operations

Stephan Franz
Project Manager Thin Film

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News Release

First Solar Becomes First PV Company to Produce 1GW in a Single Year

TEMPE, Ariz., Dec 15, 2009 (BUSINESS WIRE) -- First Solar Inc. (Nasdaq: FSLR) today announced it has manufactured and shipped more than 1 gigawatt (GW) of its photovoltaic (PV) solar modules in 2009, becoming the first PV company to attain this production volume in a single year. One gigawatt of solar modules produces enough electricity to serve the needs of approximately 145,000 average American homes and saves roughly 1 million metric tons of carbon dioxide emissions annually.

As the world's largest solar module manufacturer, First Solar has increased its manufacturing capacity from approximately 75 megawatts (MW) per year at the beginning of 2007 to more than 1GW today.

"This proof that the solar industry can achieve the manufacturing scale necessary to fight climate change is especially timely in light of the Copenhagen conference that began last week," said Bruce Sohn, First Solar president. "Our efforts in scaling our technology are critical to creating a more sustainable energy infrastructure and reducing greenhouse gas emissions."

First Solar has continually lowered the cost of manufacturing solar modules, breaking the $1 per watt barrier earlier this year.

About First Solar

First Solar manufactures solar modules with an advanced semiconductor technology and provides comprehensive photovoltaic (PV) system solutions. By continually driving down manufacturing costs, First Solar is delivering an economically viable alternative to fossil-fuel generation today. From raw material sourcing through end-of-life collection and recycling, First Solar is focused on creating cost-effective, renewable energy solutions that protect and enhance the environment. For more information about First Solar, please visit www.firstsolar.com.

For First Solar Investors

This release contains forward-looking statements which are made pursuant to the safe harbor provisions of Section 21E of the Securities Exchange Act of 1934. The forward-looking statements in this release do not constitute guarantees of future performance. Those statements involve a number of factors that could cause actual results to differ materially, including risks associated with the company's business involving the company's products, their development and distribution, economic and competitive factors and the company's key strategic relationships and other risks detailed in the company's filings with the Securities and Exchange Commission. First Solar assumes no obligation to update any forward-looking information contained in this press release or with respect to the announcements described herein.

SOURCE: First Solar, Inc.

First Solar, Inc.
United States:
Alan Bernheimer
+1-602-414-9361
media@firstsolar.com
Europe:
Brandon Mitchener
+49-6131-1443-399
media@firstsolar.com

2nd Thin Film Solar Summit US

Brian R. Murphy, PhD
President & CEO

The Power and Potential of CdTe

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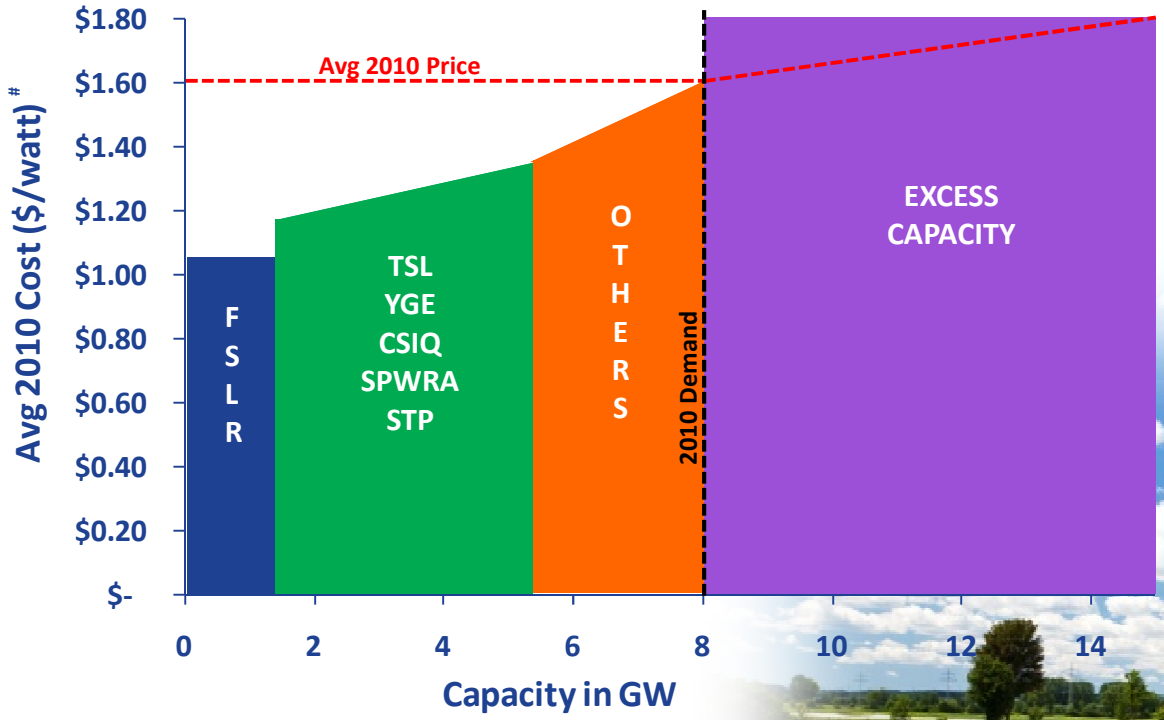
2010 PV Supply, Demand, and Opportunity

Capacity in GW vs. Average Cost for 2010*



#Cost adjusted for efficiency penalty or credit
*Source: Company data, Fulcrum estimates

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CdTe Competitive Landscape

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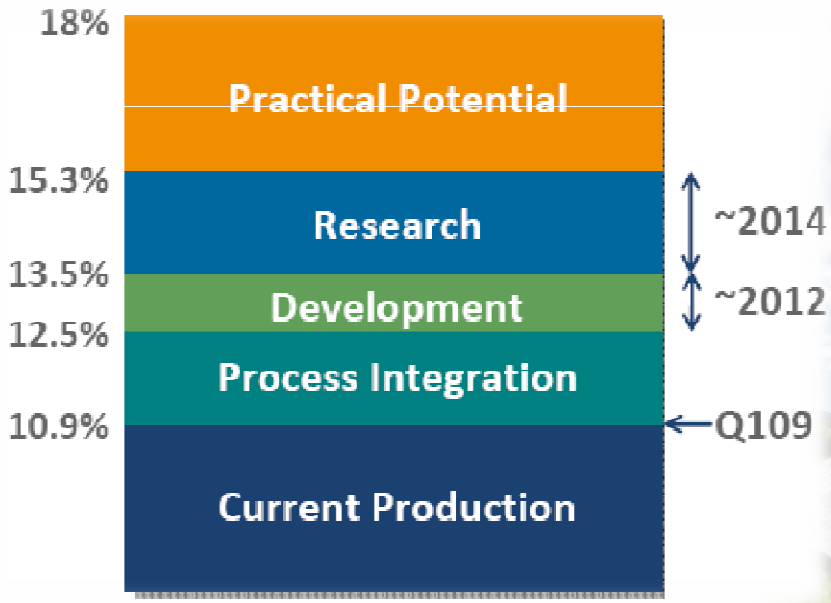
CdTe Potential

PrimeStar Solar

CdTe Technology	Lab Cell	Estimated Full Module
Present module technology		11%
NREL CdTe world record cell technology	16.5%	13%
CdTe potential with R&D improvements	19%	15%
Simulated near ideal CdTe technology	24%	19%

First Solar



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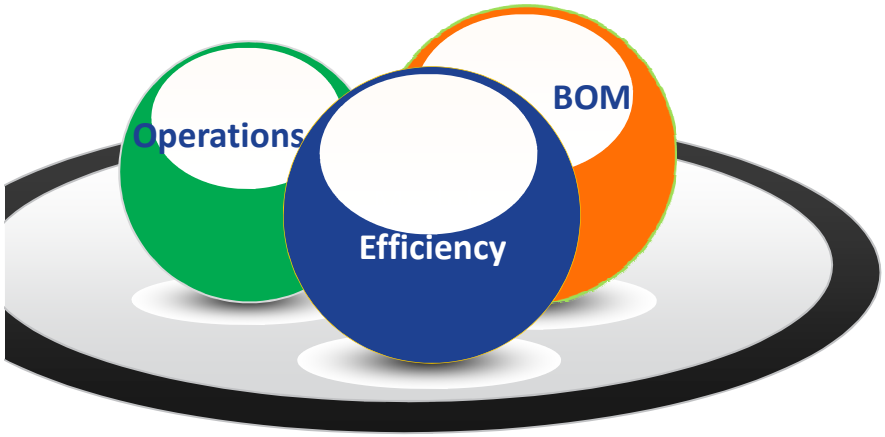
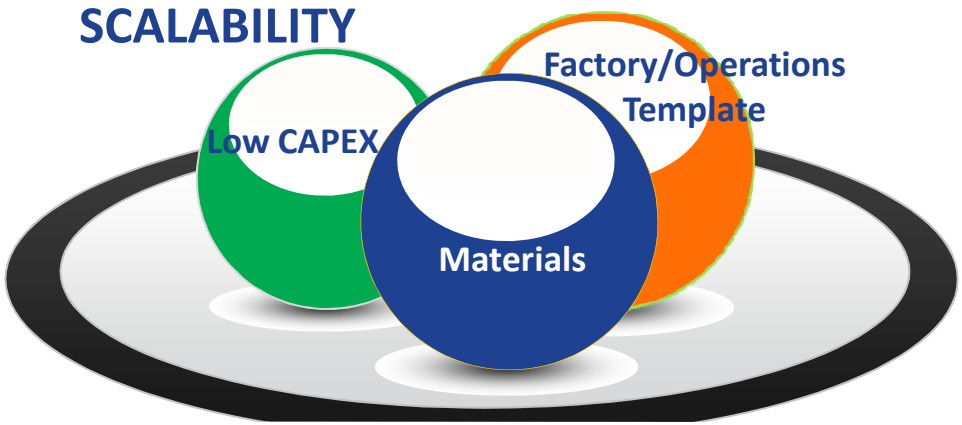
Recipe for Leadership



COST CONTROL

RISK MANAGEMENT

SCALABILITY



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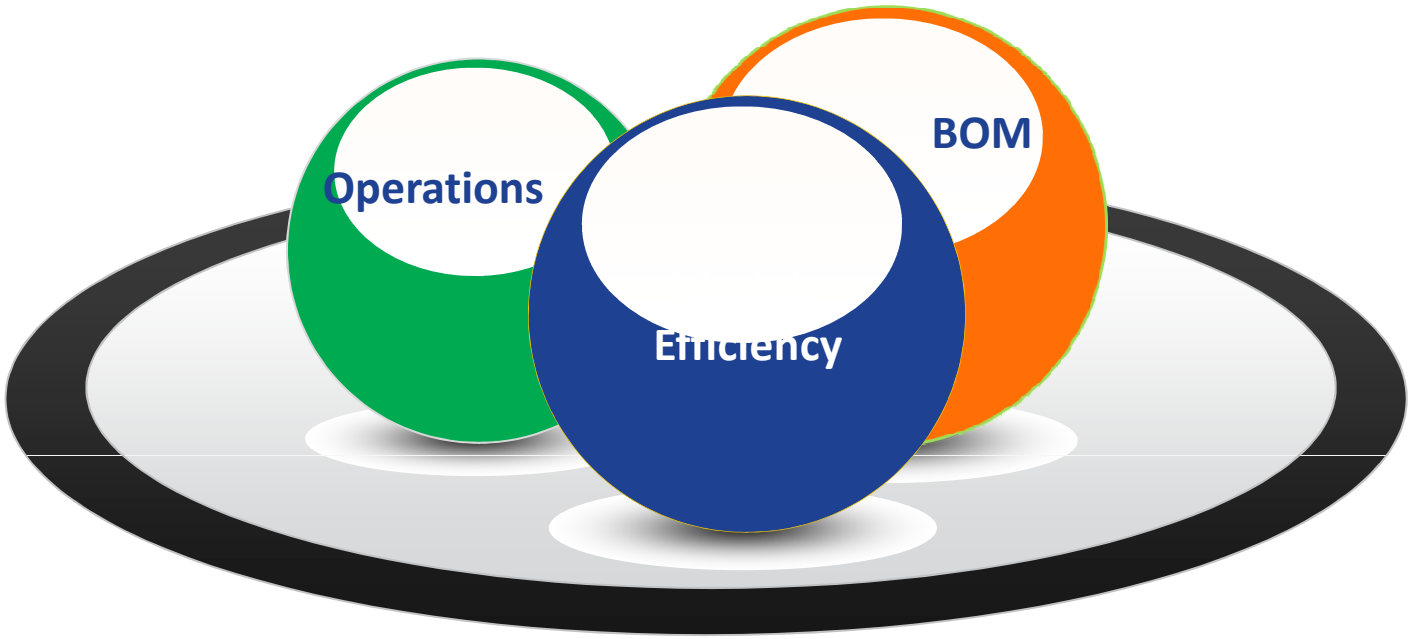
Cost Control



Cost = $0.85/watt

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Risk Management

Installed Base = 1.5 GW

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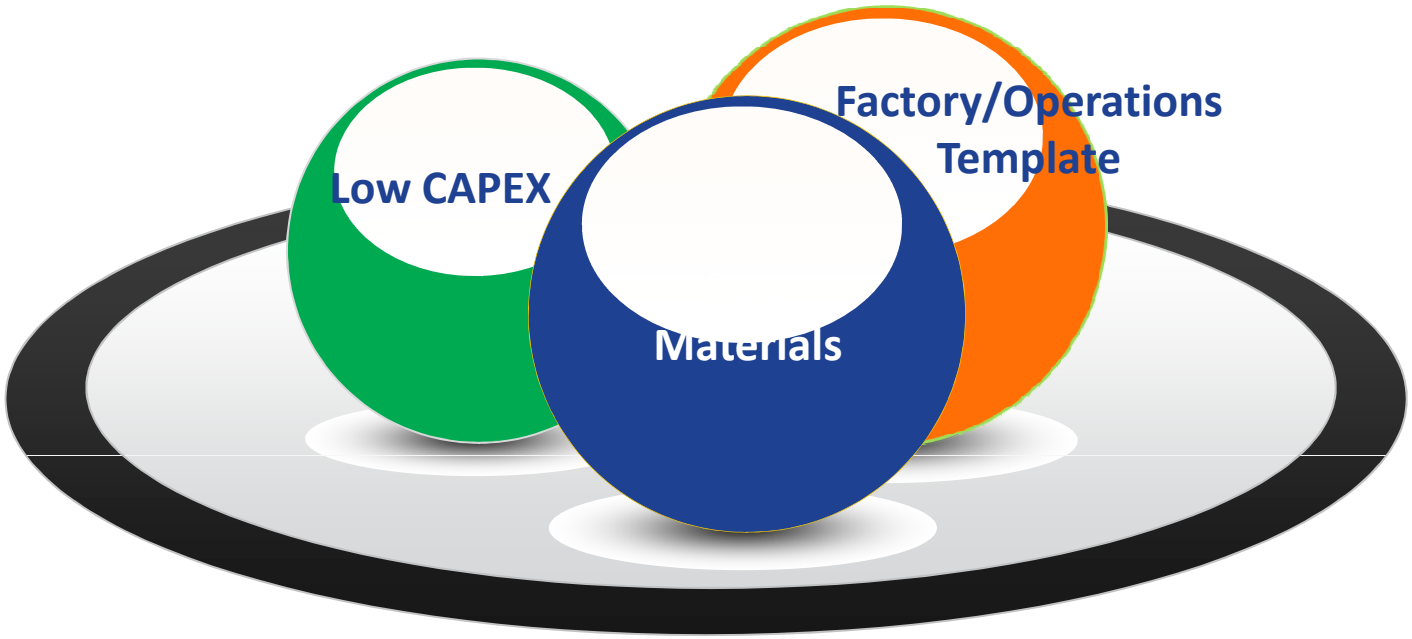
Scalability



CAPEX = $0.60/watt

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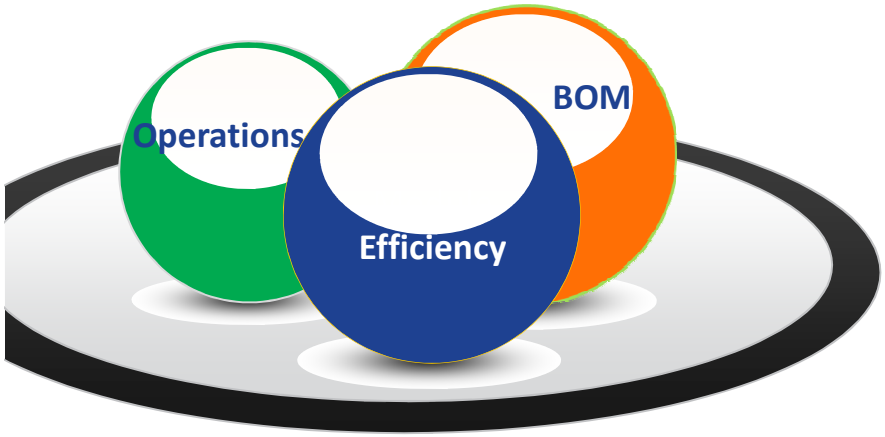
CdTe Leadership in PV



COST CONTROL

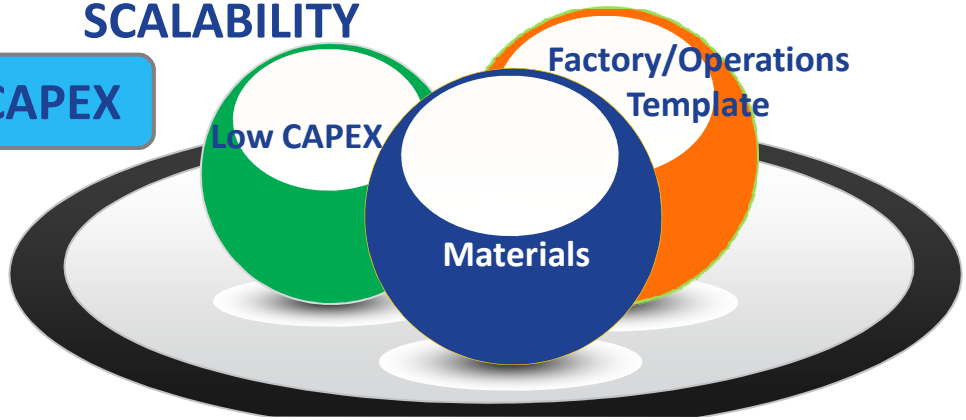
Cost = $0.85/watt

RISK MANAGEMENT

~1.5 GW installed

SCALABILITY

$0.60/watt CAPEX



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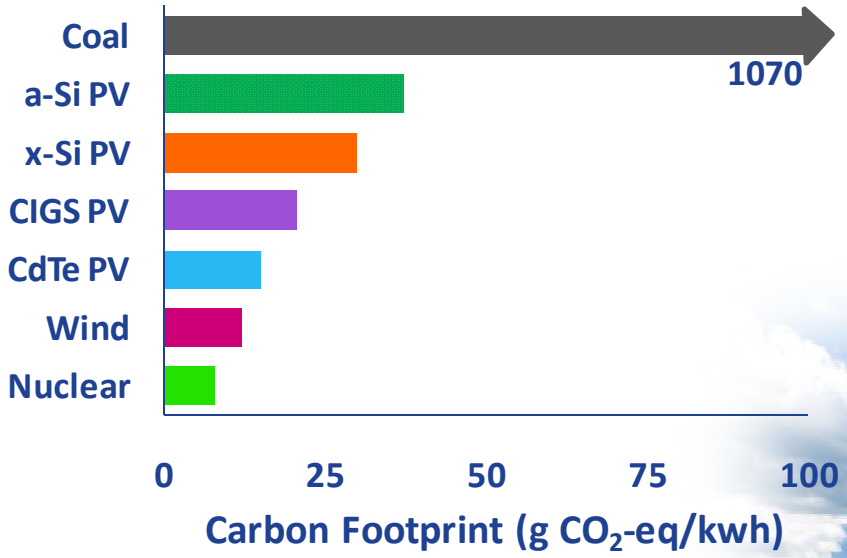
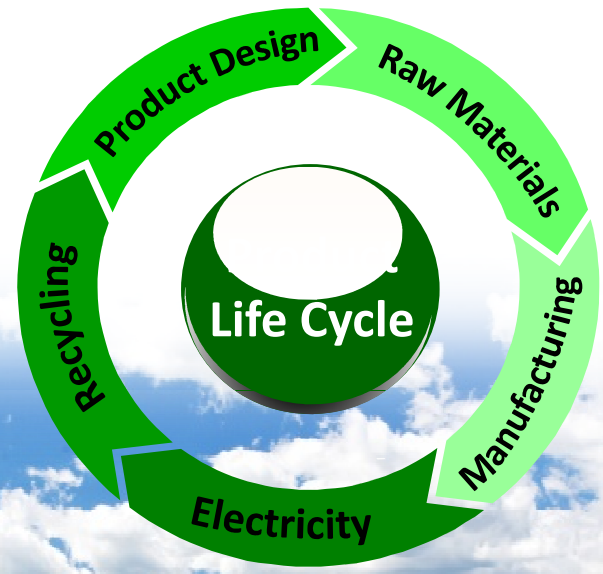
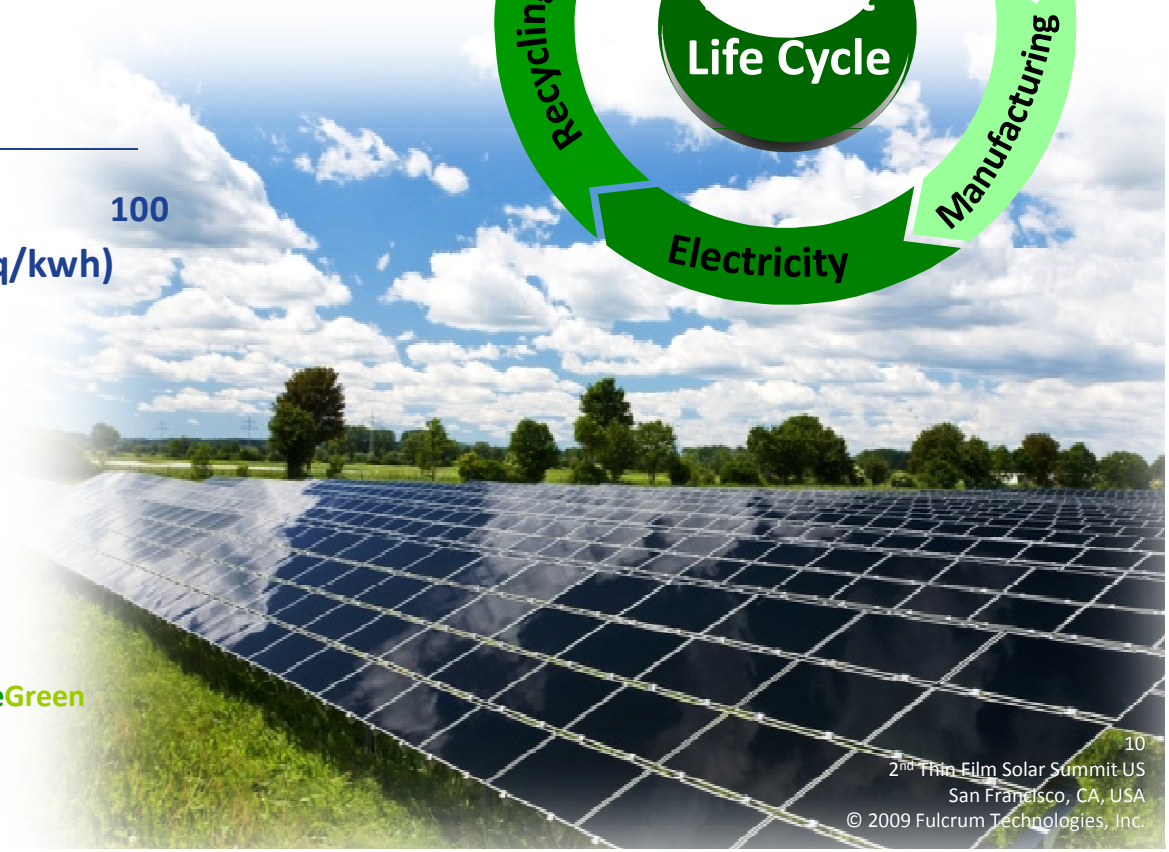
Environmental Awareness

Carbon Footprint of Electricity Generation Technologies*



#Adopted from ECN and M&W Zander presentation at Thin Film Industry Forum, Berlin, April 24, 2009





ASSOCIATION PV CYCLE

Making the photovoltaic industry **DoubleGreen**

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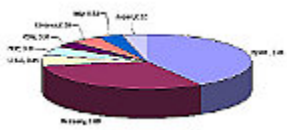
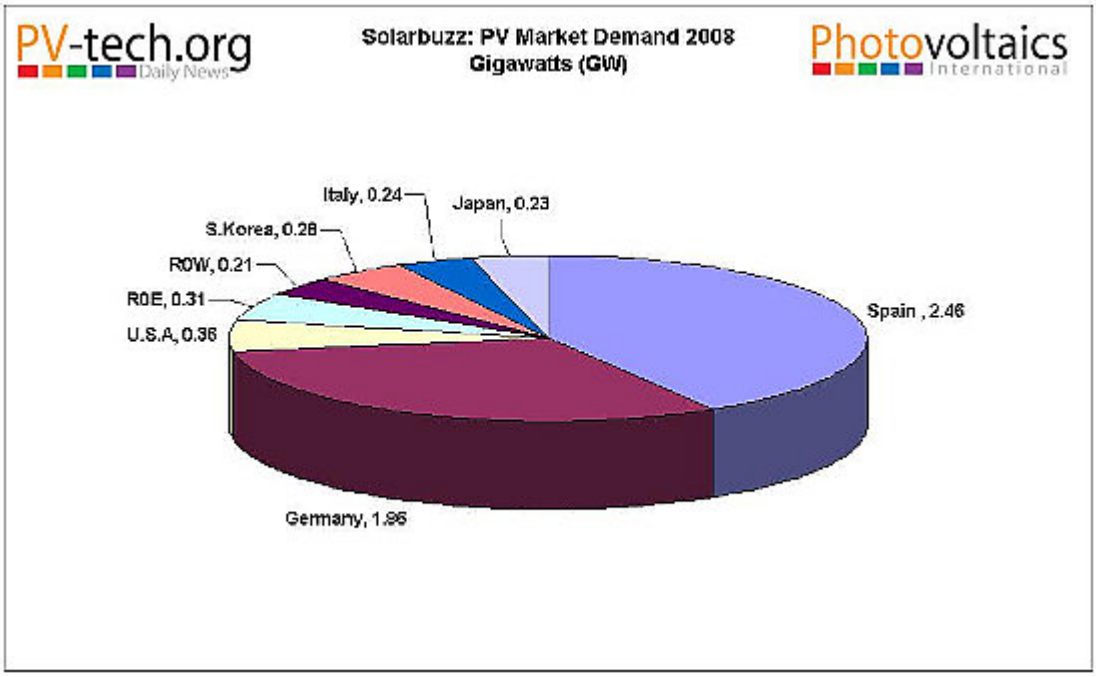
Worldwide photovoltaics installations grew 110% in 2008, says Solarbuzz

PV Tech - www.pv-tech.org



Significant growth in worldwide installations of PV modules for 2008 has been reported by market research firm, Solarbuzz LLC. Installations reached 5.95GW - a growth rate of 110% compared to 2007, which saw installations reach 2.826GW. The PV industry generated $37.1 billion in global revenues in 2008, according to Solarbuzz.

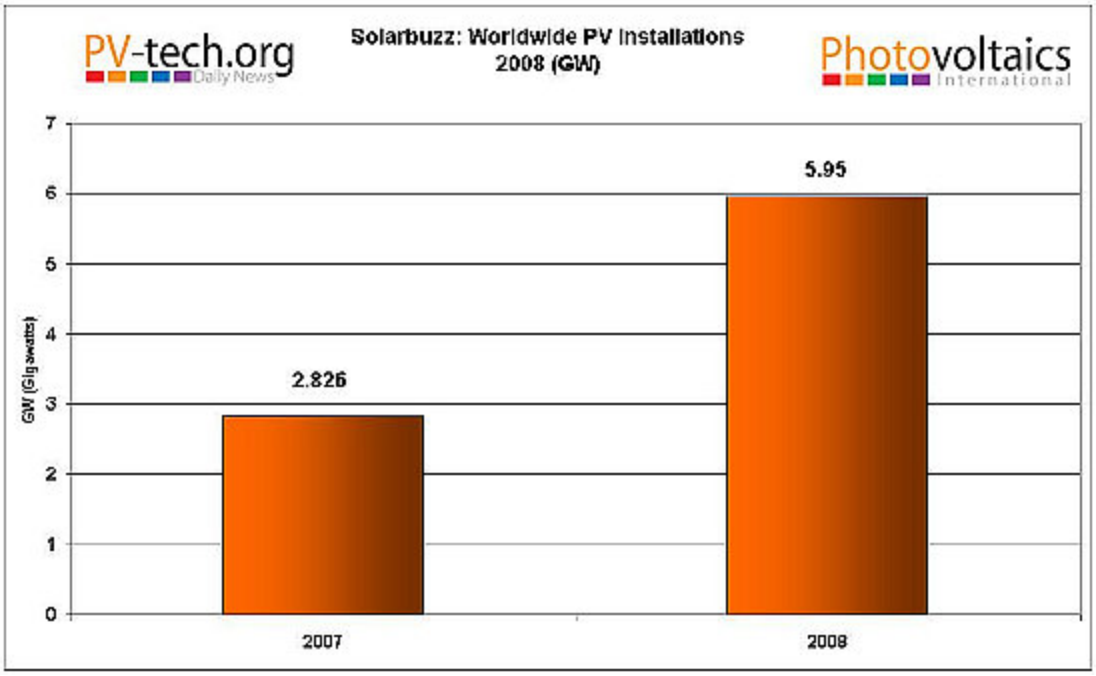


On a regional basis, Spain surpassed Germany for PV installations for the first time. Solarbuzz said that installations reached 2.46GW in 2008, compared to 1.86GW in Germany. The lack of a cap on installations, coupled to favourable FITs (Feed in Tariffs) in Spain were key factors behind the surge in installation in Spain. The Spanish Government has consequently imposed a 500MW cap on installations.

Europe accounted for 82% of world demand, strengthening its position as the key market for the PV industry.

"Twelve months ago, we projected that as early as the fourth quarter of 2008 the PV industry would no longer be constrained by solar module supply, but instead by market demand," said Craig Stevens, President of Solarbuzz LLC. "Now, the PV industry will need to navigate major changes in the regional demand mix, with new markets emerging, while addressing excess supply positions and significant adjustments to industry pricing."

Solar cell production was reported to have reached 6.85GW in 2008, up from 3.44GW in 2007. Solarbuzz noted that China and Taiwan increased their share of global solar cell production to 44% in 2008, up from 35% in 2007. Thin-film production grew by 123% to 0.89GW, according to the market research firm.



http://www.pv-tech.org/lib/printable/4872/

Published: 16 March 2009

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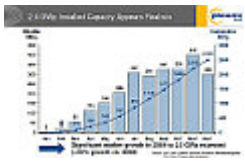
German market booming: Inverter and module supplies running out at Phoenix Solar

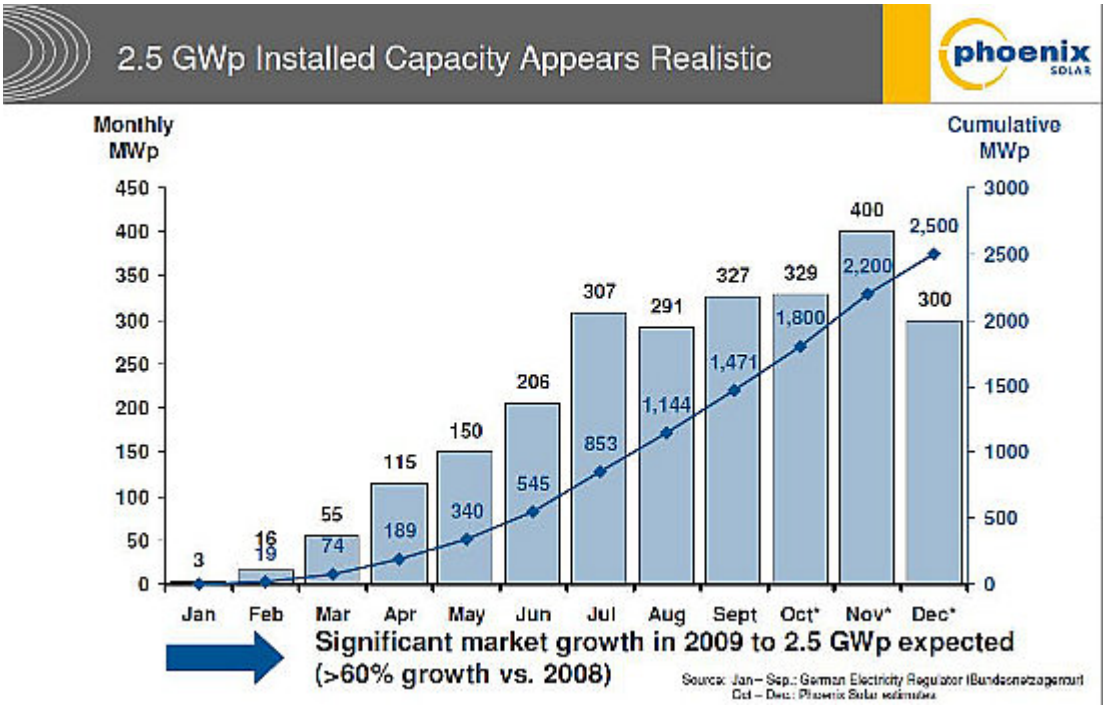
PV Tech - www.pv-tech.org



Business is back and booming at major PV systems integrator Phoenix Solar. The German residential market is overheating as the race to complete installations by year-end intensifies. According to Phoenix Solar, there will not be enough inverters and solar modules available through to the end of the year to achieve its original revenue guidance.

The company noted while delivering its third-quarter financial results that the German domestic market had been characterized by customers waiting for further module price declines in the first half the year. With prices stabilizing in the third quarter, Phoenix Solar saw a surge in orders and has even intensified in October as the race to install systems before FiT changes kick in at the beginning of 2010. With the higher profitability of systems due to the price declines, both the domestic and commercial sectors are booming.

Phoenix Solar noted that it was expecting this year to be the most seasonally extreme it has ever encountered in Germany and, although slow to start, the year will end with significant growth in installations over 2008.



The systems integrator now expects the German market to reach 2.5GW of new installations this year, a 60% increase over 2008. Indeed as recently noted by PV-Tech, the highest levels of installations are expected in the fourth quarter.

Phoenix Solar said that it expected 400MW installed in November, the highest figure ever and 300MW in December.

The only dampener in the German market this year has been the utility-scale solar project business, according to the company. The lack or difficultly in obtaining finance has limited the number of projects. Importantly, even projects that obtain finance the processes are taking longer as strict criteria by lending banks have been applied. This has contributed to project delays with many not expected to be completed until 2010.

The impact this had on Phoenix Solar can be seen with its current order backlog, which has grown to €164 million on 30 September 2009. A €105 million is attributed to its Components & Systems segment (Domestic & Commercial), while only €59 million of backlog is attributed to Power Plants segment.

Also of interest was Phoenix Solar's take on other markets it operates in. The company noted that the financing issues in the Spanish market have played a part in restricting installations to the extent that only 130MW is likely to be installed in the country, despite the 500MW cap. In 2008, 2.6GW was installed when the FiT system was uncapped and more lucrative.

However, the Spanish market could be improving since delays in projects could finally ease as plants approved in the first quarter of the year need to be built by the end of the first quarter of 2010 to be accepted into the

current FiT.

The Italian market has also been wise to the rapid module price declines through the first half of the year as installations actually slowed. With better price stability and a tightening of supply, demand has come back which could result in 250MW installed this year.

The French market is also improving but faces long approval processes, hampering installations. Even so, the French market is expected to reach 150MW this year.

Module and inverter shortages

Looking at Phoenix Solar's suppliers list it quickly becomes apparent why the systems integrator is struggling to get the supplies it needs.

Having made a conscious decision to boost its reliance on thin-film module technology when large-scale commercial and utility-scale projects dominated the German market in 2008, its c-Si supply base is limited. However its thin-film suppliers are also limited in meeting demand.

Phoenix Solar has major supply agreements with First Solar, which highlighted that it was at full capacity in the previous quarter and had shipped all product produced in the quarter and has no more new capacity coming onstream in the short term. Another thin film supplier is start-up Solyndra, which has a claimed US$2 billion order backlog and limited production capacity until a second plant is built.

The story is similar with other thin-film suppliers such as Signet Solar, Schott Solar and Sharp. All have limited capacity. Sharp also has the challenge of meeting renewed demand from the Japanese domestic market, limiting overseas supply as margins are better in selling into Japan. Sharp will not have its new thin-film plant operational until early next year.

As for c-Si module suppliers, listed suppliers are Sharp, Schott Solar, Suntech and Yingli Green. Major suppliers are predominantly Asian-based and shipment times extended. Phoenix Solar noted that orders placed in September with these suppliers would be used for projects in the fourth quarter and were already allocated.

However, suppliers such as Yingli noted in their most recent quarterly results that it had raised its annual PV module shipment target to an estimated range of 490MW to 500MW, which suggests that with a current nameplate capacity of 600MW, the supply of modules is constrained.

Indeed, Yingli executives said in its third-quarter financial conference call that the factories were running at 100% utilization in the quarter and due to forward bookings would remain at that level through first-quarter 2010. Currently, Yingli has not yet announced any further capacity expansions plans for 2010.

In the first quarter of next year, Yingli is expecting the yields and operational efficiency gains to boost MW capacity.

Inverter supplier SMA also noted record quarterly results last week and is also capacity constrained as inverter output sold went from 200MW in Q1 to 1.2GW in Q3.

Phoenix Solar assumes that revenues will settle within a corridor of between €430 and €480 million in 2009, up from revenue of €402.5 million in 2008 but down from previous guidance of €520 million.

http://www.pv-tech.org/lib/printable/6694/

Published: 15 November 2009

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Print

October 4, 2010

Germany Adds Nearly 1% of Electricity Supply with Solar in Eight Months

by Paul Gipe, Contributor

Seemingly determined to put an end to speculation that solar photovoltaics (PV) can't "scale" quickly enough to make a dent in electricity consumption, the German solar industry continues to break records.

According to the latest data from the *Bundesnetzagentur*, Germany's solar industry added another 1,000 MW during July and August. This brings the total for the eight-month period from January through August to 4,900 MW from nearly 175,000 solar installations.

Solar PV installations to date in 2010 are capable of generating slightly less than 5 TWh of electricity under German conditions.

Germany 2010 Solar PV Installations

	MW	Units
Jan	225	7,300
Feb	162	6,550
March	328	16,900
April	449	20,500
May	563	24,000
June	2,126	65,400
July	670	21,000
Aug	360	11,900
	4,883	173,550

Germany consumed 580 TWh of electricity in 2009.

Installations of solar PV during the first eight months of 2010 are capable of providing 0.86% or nearly 1% of the country's electricity. At the current pace of development, Germany will add about 6,000 MW of PV for all of 2010 or more than enough to provide 1% of electricity supply.

Germany currently meets approximately 1% of its supply with solar PV. With the 2010 additions, the country will meet 2% of its supply with solar PV.

Wind energy supplied 6.5% of Germany's electricity in 2009. Germany is expected to add another 4 TWh of generation from wind energy in 2010 or somewhat less than 1% of consumption.

Critics of solar energy have often charged that solar could not be scaled or installed quickly enough to have a significant effect on electricity supply. It is now clear that solar PV can indeed scale where the policies are designed to do so.

France

In other markets, France installed 200 MW of solar PV during the first six months of 2010, bringing total installations to 510 MW. There are 3,700 MW of solar PV projects and another 4,700 MW of wind projects awaiting interconnection.

North America

New Jersey's Clean Energy program estimates that, at the current pace, 125 MW of solar PV will be installed by year end, bringing total installations to nearly 250 MW.

The Canadian Solar Energy Industries Association (CanSIA) estimates that 100 to 200 MW of solar PV will be in installed in Ontario during 2010.

Industry analysts ClearSky Advisors estimates that total solar PV capacity in Ontario could reach nearly 700 MW by the end of 2011. Total PV installations could reach 3,000 MW by 2015.

In a related development, Italian solar manufacturer SilFab has announced that they will set up an assembly plant in a Toronto suburb and plan to produce 60 MW of solar PV in 2011.

On October 7, Enbridge, a Canadian operator of oil and natural gas pipelines, will dedicate the world's largest solar PV plant near Sarnia, Ontario. The 80 MW plant was begun by defunct California solar company Opti-Solar but was completed by Ohio's First Solar.

Ironically, North America's first commercial oil wells were drilled near Sarnia in 1858 and the region remains the center of the oil and chemical industry in Ontario.

In 2009, California added 200 MW of solar PV.

The US installed 435 MW of solar PV in 2009.

null

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CHADBOURNE
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PROJECT FINANCE
NewsWire

April 2010

Strategies for Starting Construction

by Keith Martin and John Marciano in Washington, and Eli Katz in New York

The race is on to get renewable energy projects in the United States under construction by year end to qualify for cash grants from the US Treasury.

Developers are pursuing different strategies.

It is not enough merely to have made a large down payment toward turbines, modules or other equipment for the project by year end. A senior Treasury source said the government is looking for economic activity during 2010. A developer must show work at the site or at the factory on equipment for the project during 2010.

The grants are 30% of the project cost and are paid on new wind, solar, geothermal, biomass, landfill gas, waste-to-energy, ocean energy and fuel cell projects that are completed in 2009 or 2010 or that start construction in 2009 or 2010.

Grants of up to 10% of project cost are also paid on small cogeneration facilities of up to 50 megawatts in size.

Projects that merely start construction in 2010 must be completed by a deadline. The deadline is 2012 for wind farms, 2016 for solar, small cogeneration and fuel cell projects and 2013 for other types of projects.

Congress may ultimately give companies more time. A bill in the House would give developers another two years through December 2012 to start / continued page 2

IN THIS ISSUE

1 Strategies for Starting Construction
5 Germany Cuts Solar Subsidy
8 Update: Tax Equity Market
20 Swap Gets Wholesale Generator Into Trouble
22 Tax Credits for Green Manufacturers: Who Will Use Them and How
27 Court Orders Lender to Continue Funding Defaulted Loan
28 Shedding Assets Quickly in Bankruptcy
34 Environmental Update

IN OTHER NEWS

UNCERTAIN TAX POSITIONS will have to be flagged on US tax returns starting this year using a new form the Internal Revenue Service released in mid-April.

The form — called a Schedule UPC — will have to be attached to corporate tax returns filed for 2010.

The IRS hopes that forcing corporations to disclose tax positions about which they are uncertain will save the government time in tax audits. Critics speculate that IRS agents will be able to save even more time by simply disallowing all the positions a company identified.

The forms will have to be filed for now only by / continued page 3

This publication may constitute attorney advertising in some jurisdictions.

Germany Cuts Solar Subsidy

by Dr. Till Vogel, with Schiedermair Rechtsanwälte in Frankfurt

The German federal cabinet decided in early March to reduce feed-in tariffs for newly-built solar photovoltaic projects in Germany by an average of 15% starting July 1, 2010. Another 9% is already scheduled to take place on January 1, 2011.

The plan must still be approved by the Bundestag, or the German parliament. Some changes are possible before the bill implementing the plan is approved

The lower tariffs will apply to projects that go into service on or after the dates set for tariff reductions.

The tariffs were already cut by 9% at the start of 2010. They currently run from 37.14¢ to 28.43¢ a kilowatt hour depending on the size of the project and its location. The feed-in tariff is the amount that utilities in Germany are required by law to pay for electricity offered to them — in this case from photovoltaic facilities. Total installed generating capacity from solar in Germany is 8,877 megawatts from photovoltaic installations. There are currently no concentrating solar power projects (also known as solar thermal). The tariff is the same for both types of solar.

The feed-in tariffs have been declining over time, but they normally decline only once every year. When Germany first instituted them in 2000, they were 62.4¢ per kWh.

The latest plan would lead to a total reduction in the feed-in tariff for PV energy of almost 30% within a 13-month period. As the feed-in tariff is guaranteed by law for the year of the connection to the grid plus the following 20 calendar years, the amount is important for financing PV projects. The latest measures mean a significant loss of revenue over 20 years if a project starts too late.

Reductions Vary

The feed-in tariffs for electricity generated in roof-mounted solar systems will be reduced by 16% if the system is connected to the grid after June 2010. The relevant date for the calculation of the feed-in tariff for a German PV project under the regime of subsidies is the day of the first power supply into the grid. Thus, commencing power sales on July 1 rather than June 30 can cost a developer a lot of money.

The reduction of the feed-in tariffs for / continued page 6

IN OTHER NEWS

signed a bill to waive the taxes in early April.

The bill is not effective until January 1, 2011, but will be retroactive to 2009 and 2010 once it takes effect. The Franchise Tax Board said in the meantime that it does not plan to collect taxes on grants paid in 2009 and 2010.

WYOMING will start collecting an excise tax of $1 a megawatt hour from wind generators in the state. The tax will apply to electricity generated after 2011. It will apply on a turbine-by-turbine basis, but will not be collected until the turbine has been in use for at least three years.

The state legislature debated setting the tax at anywhere from a penny to $5 a mWh before settling on $1. It delayed the effective date to allow time to study the potential effect on the wind industry.

INDIA reaffirmed in late March that companies based in Mauritius do not have to pay capital gains taxes when they sell shares they own in Indian companies.

An E*Trade subsidiary in Mauritius sold shares in an Indian company to an HSBC investment vehicle also in Mauritius. The sale generated a long-term capital gain for E*Trade. The Indian authorities challenged E*Trade on its position that it was entitled to an exemption from capital gains taxes in India under article 13(4) of the India-Mauritius tax treaty, which says that a Mauritius resident can only be taxed in Mauritius on its gains, arguing that the E*Trade subsidiary in Mauritius was merely a shell company and the real owner of the shares in the Indian company was the E*Trade parent company in the United States. The Indian authorities directed HSBC to withhold 21.11% of the sales price for the capital gains taxes. E*Trade appealed.

The Authority for Advance Rulings held that India had to honor the treaty exemption, ruling essentially that there is no prohibition against treaty shopping. It also / continued page 7

German Solar

continued from page 5

electricity from ground-mounted PV systems installed on so-called redeveloped areas — for example, former military sites or former landfills — is not as painful as for roof-mounted systems. The reason for this is purely political. The intention is to promote the use of such real estate for PV systems as they are of limited use for other purposes. Furthermore, the investors run the risk of having to deal with environmental pollution on such sites. Thus, the reduction of the feed-in tariffs for projects in such locations is only 11%.

For other areas, the tariff will be reduced by 15%.

Feed-in tariffs will be eliminated for ground-mounted PV systems installed in areas that are defined as "farm land." This has been a subject of intensive discussion. Opponents argue that it is unethical to produce electricity on land that could feed humans while people starve and prices for food rise. From July 1, 2010 on, there will no longer be an obligation for grid operators to buy and remunerate solar companies using "farm land" to generate electricity. Since there are a lot of projects already in the pipeline, there needs to be a transition arrangement for these projects. The bill provides "grandfather" relief. The current tariff would continue to apply to projects that are already in an advanced stage of development, were approved by the local authorities by an official development plan before the end of 2009 (although this date is currently under discussion) and will be built and connected to the grid by the end of 2010.

In order to compensate for the loss of "farm land" for solar development, the cabinet suggested that trade and industrial areas as well as areas along motorways and railways (the latter in 100- to 200-meter-wide strips) should be included on the list of areas on which PV systems can claim special promotion under German law. Systems in such areas will be eligible for the feed-in tariff in the future.

Although such changes in the guaranteed feed-in tariffs have been foreseeable since the current black-yellow government formed its coalition in Berlin, the amount of the reduction is surprising.

Also the complete ban of ground-mounted PV systems on "farm land" was unexpected.

The German PV industry now claims that it is being strangled and that the number and size of new PV projects in Germany will drop significantly with a cost of thousands of jobs in the national PV industry. The government responds that since the price of solar power equipment (especially solar modules) dropped significantly during the last 18 months, solar projects have become more profitable leading to an "over-promotion" of new projects by the current tariffs.

Under the German law, the local grid operator has to connect every PV plant to its grid and to purchase all electricity generated as well as to pay the feed-in tariffs provided for by law. German law guarantees a constant feed-in tariff for the year in which the plant starts to supply electricity into the grid and the following 20 calendar years. The details are in an "Act on Granting Priority to Renewable Energy Sources." The grid operator can pass through all these amounts to its customers as an add-on fee to the regular electricity invoices. Thus, the subsidies are paid ultimately by all electricity consumers in Germany. To the extent electricity from solar costs more than from other sources, this becomes a burden on the German economy. The current German government wants to slow the rate at which Germany is adding to this burden by cutting tariffs which, in turn, will mean fewer new projects.

Lobbyists from the solar industry have mobilized and are working on the politicians from both partners of the black-yellow coalition in Berlin. These efforts have already met with some success: only two weeks after the declaration by the federal cabinet, the prime minister of Bavaria — which is one of the southern states and thus hosts more solar projects than any other state in Germany — demanded changes in the federal plan. Perhaps surprisingly, it appears that the coalition is willing to follow this demand and will provide for a longer transition period to allow projects that are currently under development to be completed under the existing tariff. More changes are possible before any plan is adopted by the Bundestag.

Significance?

So what does all this mean for investors and banks who are engaged in the PV business in Germany?

For those who have German PV projects in the pipeline, the best advice is to watch the legislative process closely and try to qualify for grandfather relief under whatever transition rule is adopted. Currently the bill states that PV plants already operating are not affected at all by the changes. It should be safe to assume that this will not change. Any retroactive reduction in tariffs would be declared unconstitutional by the federal constitutional court.

Also, PV plants that start to feed energy into the grid before the key dates (July 1, 2010 or possibly October 1, 2010) will not be affected by the changes for the same reasons.

Only plants that start to feed electricity on or after July 1, 2010 (or whatever date is chosen ultimately) are affected by the new tariffs. As the construction period for a PV project is in some cases longer than the three months remaining until July, this means that some projects that were planned, calculated, funded and developed under the old feed-in regime could be hit hard. Developers in such a position will have to decide whether to start construction or cancel their projects.

To soften the hardship, the bill grants a grace period for very large countryside projects that are already under development. Such projects can be built and connected to the grid until the end of this year and still receive the existing feed-in tariff until 2030 if the competent local parliament had already agreed to the project by December 31, 2009 and has granted the permission to build the plant. However, for all other types of PV projects, especially the very popular roof-mounted systems, this transition rule will not apply. Therefore, there is now tremendous time pressure to finish construction of these projects before July 1, 2010. In case of some large projects, this will not be possible.

Upside

The bill is not only a one-way street. It increases some subsidies.

Under the current German regime, there is a financial incentive for owners of smaller PV plants (such as private households) not to feed the electricity into the grid but to use the energy for themselves on site. If an owner does so, he receives an incentive payment from his grid operator. The owner receives this money and also avoids having to buy electricity from the grid. Thus, householders are better off than if they sold to the grid. The bill increases this incentive from 3.6¢ to 8¢ per kWh. The incentive will also be extended to larger PV systems with outputs of up to 800 kilowatts. However, the incentive payments to owners of such larger systems are reduced to the extent the price the homeowner would be charged to buy electricity from the grid is less than 20¢ a kWh. This is the benchmark price in the bill.

Further reductions in the feed-in tariff will occur at the rate of 9% a year. However, the rate could increase to 11% a year if additionally installed PV capacity reaches 3,500 megawatts a year. The national target for / continued page 8

IN OTHER NEWS

questioned the continuing viability of the treaty.

The Mauritius treaty used to confer two benefits. One was a reduced withholding tax on dividends received from Indian companies. The other is an exemption from capital gains taxes. India cut off the withholding tax benefit by converting its withholding tax to a tax on the Indian company paying the dividend. It has periodically fought exemption claims on capital gains taxes.

In 2000, the Central Board of Direct Taxes said in Circular 789 that Indian tax collectors must honor certificates of tax residency from the Mauritius authorities. The circular was temporarily set aside by the Delhi high court before being reinstated by the Supreme Court in 2003.

The Indian government is moving to replace its existing income tax code with a new "direct" tax code. The proposed new tax code would give the government additional tools to ignore the form of transactions and focus on the substance, for example by declaring transactions as "impermissible avoidance arrangements." This may be used to attack treaty transactions.

In a related case, an income tax appellate tribunal in Mumbai held in March that a service company in Dubai could take advantage of the India-United Arab Emirates tax treaty to avoid withholding taxes on fees that the Dubai service company, Caltex, received from an oil refinery in India.

Caltex could only benefit from the treaty if it was "liable to tax" in Dubai. It did not pay any taxes in fact. The tribunal cited a Canadian court decision for the proposition that actual current taxation is not required; it is enough that Caltex could be taxed in Dubai should the government choose to tax it. The case is *Hindustan Petroleum Corporation, Ltd. v. ACIT.*

BUILD AMERICA BONDS now constitute more than 20% of the municipal bond market, the US Treasury Department said in April.

The bonds are taxable / continued page 9

German Solar

continued from page 7

the growth of PV capacity in Germany is being raised from 1,700 megawatts to 3,500 megawatts per year. Once the growth of installed PV capacity exceeds 3.500 megawatts, then the feed-in tariffs will be reduced automatically by an additional 2% a year on top of the 9% annual reduction. On top of the scheduled reduction of 9%, tariffs will be reduced at the end of 2011 by another 3% for every 1,000 megawatts of additional growth in PV capacity above the national target. On the other hand, the bill provides that if the market growth in production capacity leaves Germany below a minimum limit of 2,500 megawatts per year, then the feed-in tariffs decrease more slowly. The 9% normal rate of reduction would be shaved by 2.5% for every 500 megawatts that installed capacity is below the minimum limit.

Update: Tax Equity Market

Most renewable energy projects in the United States have been financed in the past largely with tax equity. The US government pays as much as 65% of the capital cost of such projects through tax incentives. Few developers can use the incentives directly, so they barter them in tax equity transactions to raise capital for their projects.

The tax equity market largely collapsed after Lehman went bankrupt in September 2008. Congress reacted by directing the US Treasury in an economic stimulus bill in February 2009 to pay owners of new renewable projects completed in 2009 or 2010, or that start construction in 2009 or 2010, 30% of the project cost in cash in place of part of the tax incentives. The tax equity market started to revive after the Treasury issued rules implementing the 30% cash grant program in July 2009. There were at least 15 active tax equity investors by April 2010, down somewhat from the number before the market collapsed.

The following is an edited transcript of a discussion among six of the largest tax equity investors about the state of the market at an Infocast wind finance summit in late February in San Diego. The panelists are John Eber, managing director of energy investments for JPMorgan Capital Corporation, Jeetu Balchandani, director of private securities, structured leasing and tax investments at MetLife, Jack Cargas, managing director of energy and power finance at Bank of America, Lance Markowitz, senior vice president of the equipment leasing division at Union Bank of California, Marshal Salant, a managing director at Citigroup, and Jerry Smith, a managing director at Credit Suisse. The moderator is Keith Martin with Chadbourne.

MR. MARTIN: What do you see in the year ahead for the tax equity market?

MR. MARKOWITZ: It will be a much stronger year than 2009. We should see a large number of deals. There will be more variety in deal structures. There are more tax equity investors in the market.

MR. BALCHANDANI: The pipeline of deals expected to come to market this year suggests a demand for tax equity that will far outstrip the supply. Anyone looking for tax equity in 2010 should keep in mind there will be limited capacity. Start talking to potential tax equity investors as early in the year as possible.

MR. SALANT: I agree with the point that was just made. Demand for tax equity could easily reach $10 billion a year in 2010 and 2011. If JPMorgan takes $1 billion, we take $1 billion and each other person at this table takes $750 million, you are still $5 billion short, and it is not a simple matter for any of us to close on that volume of transactions this year. The days of casual dating are over in tax equity investing. Tax base is a precious commodity. Investors will want to preserve it for use with their most important relationship clients.

MR. EBER: More deals were done last year in the tax equity market than I think most people realize. We counted 19 wind tax equity deals that reached funding last year for total tax equity of $1.8 billion. That is about half of the tax equity invested in wind in 2008, but it is still a lot more than most people expected given how weak the economy was in 2009.

The most interesting thing about 2009 — and it will continue into 2010 — is that wind developers have options. The US Treasury is paying the cash value of the tax credits on wind farms. Wind companies no longer need to use tax equity, and a lot of companies did not last year. There was a lot of debt raised. Over $5 billion in debt went into wind farms in 2009, more than double the amount of debt the year before.

I agree that tax equity remains scarce. We will see the gap between demand for and supply of tax equity filled with debt.

MR. MARTIN: You said 19 deals last year. How many involved cash grants? How many were legacy deals where tax equity investors committed in 2008 but did not fund until 2009?

MR. EBER: Eight of the 19, or about half, were carryover,

RETI Net Short Update

Evaluating the Need for Expanded Electric Transmission Capacity For Renewable Energy

Introduction to the RETI Net Short

Modifications to California's electric transmission system will be required to accommodate state energy policies and changes in demand while maintaining reliability. The Renewable Energy Transmission Initiative (RETI) is responsible for identifying conceptually changes likely to be needed for the state to satisfy a 33% Renewable Portfolio Standard (RPS). In order to do so, the amount of additional renewable energy which will require transmission access must be quantified. That additional renewable energy is referred to as the "RETI Renewable Net Short".[1]

The RETI net short value depends on many factors which are discussed below. Most of these factors have been evaluated by the California Energy Commission (CEC) in its energy demand forecast, a component of the Integrated Energy Policy Report (IEPR). Previous estimates of the RETI net short[2] relied on the 2007 forecast. The CEC demand forecast has recently been revised significantly in the 2009 IEPR.[3] This document describes the revised estimate of the RETI net short based on the latest demand forecast and also includes a low load scenario that reflects the CEC post-IEPR report, "Incremental Impacts of Energy Policy Initiatives Relative to the 2009 Integrated Energy Policy Report Adopted Demand Forecast" as well as updated information on incremental CHP and incremental producer side of the meter DG.

Not all of the factors which determine the RETI net short value have been evaluated by the CEC or other agencies.[4] Previous net short estimates have largely ignored these factors.[5] The numerical value reported in this document, 52,764 gigawatt-hours (GWh), is consistent with RETI's previous methodology.

In order to finalize a credible conceptual transmission plan, however, all significant factors which influence the net short value must be evaluated. In addition to reporting the net short value determined by the earlier methodology, this document also discusses factors which have not yet been evaluated and which will determine the net short value appropriate for renewable transmission planning.

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[1] The RETI net short is referred to in this document as simply the "RETI net short" or the "net short". RETI's net short terminology may differ from other applications which do not distinguish between additional renewable energy which requires transmission and renewable energy which does not.

[2] Earlier estimates of the RETI net short can be found in the RETI Phase 1B Report and in the Phase 1B Update Report available on the RETI web site at http://www.energy.ca.gov/reti/index.html.

[3] California Energy Demand 2010-2020, CEC Publication Number CEC-200-2009-012-CMF. The document and associated data forms are available at http://www.energy.ca.gov/2009publications/CEC-200-2009-012/index.html. The uncommitted energy efficiency forecast is out for comment and its results are reflected in the low load scenario presented in Appendix B.

[4] The CEC demand forecast methodology considers expected changes that have been planned for by utilities and approved by utility regulators. Changes which might reasonably be expected but are not included in approved plans are not included in the demand forecast.

[5] The exception was the RETI estimate of incremental photovoltaic (PV) generation which was discussed in the Phase 1B Update Report. See Footnote 2.

Summary of Changes in the Net Short from Previous Update

The largest changes in the net short from RETI's previous value are due to changes in projected electricity demand resulting from the recent recession.[6] RPS energy procurement requirements are based on retail sales by load serving entities (LSEs.) Changes in LSE retail sales from the values used in the February, 2009, net short update are shown in Table 1 below:

RETI Net Short Estimates 2009 & 2010 (GWh)			
	LSE Retail Sales	**Existing Renew.**	**RETI Net Short**
February 2009	308,070[7]	36,807	59,710
January 2010	285,734	38,174	52,764

Table 1 – RETI Net Short Estimates 2009 & 2010 (GWh)

A second major factor contributing to the decline in the net short estimate is the increase in "existing" renewable energy believed to be on line at the end of 2009 compared to 2008. This February 22nd version of the report also includes a low load scenario that reflects incremental impact estimates for Energy Efficiency programs after 2012, for additional CHP development and for producer side of the meter distributed generation. The low load scenario indicates a net short of 36,926 GWh, however it should be noted that the low load net short is based on estimates of incremental impacts that are highly uncertain. Several other minor changes are discussed later in this document.

Caveats to the Net Short Calculation

The net short values shown in Table 1 have two important caveats: Projections are inherently uncertain. For example, the CEC demand forecast relies on uncertain projections of economic growth. In addition to the reference economic forecast the CEC also considered a more economically optimistic case and a more pessimistic case. Projected demand in these two cases differed from the reference case by about ± 2%.[8] The corresponding uncertainty in the 2010 net short is about ± 2,000 GWh, about ± 4%, as shown by the Net Short Calculator.[9]

In addition to inherent uncertainty in the inputs to net short calculations, appropriate values for producer side of the meter distributed generation have not yet been produced by the CPUC's Renewable Energy Distributed Energy Collaborative (ReDEC).[10] Moreover, values for incremental producer side DG, CHP and Energy Efficiency are highly uncertain and thus use of these inputs for purposes of transmission planning is somewhat controversial. All of these incremental inputs to the net short calculation *lower* the net short value further and the low load scenario takes a first look at what these impacts could be.

Efforts are underway by RETI and elsewhere to evaluate all of the factors needed for improved projections of new California transmission capacity needed for renewable energy. As this information becomes available, the RETI net short value will be updated accordingly. In the

[6] California Energy Demand 2010-2020.
[7] The IEPR has a 10-year forecast horizon; the 2007 IEPR included LSE sales projections to 2018 which were extrapolated to 2020 for RETI by CEC staff.
[8] California Energy Demand 2010-2020.
[9] An Excel spreadsheet version of the Net Short Calculator is available at XXX. Users can modify inputs to the Calculator to examine the resulting impact on the RETI net short. See Appendix A.
[10] Preliminary technical potential results were produced for presentation to the ReDEC in December, 2009, but to date an estimate of producer side of the meter DG market potential that is feasible by 2020 has not been produced.

meantime, renewable energy planning activities relying on the RETI net short should be cognizant of the limitations associated with the value reported in this document.

Evaluating the Need for Renewable Transmission

Provision of Energy Services

Planning for the electricity sector is best considered in a broader energy context, since changes in another sector may change the use of electricity. The major components are shown in Figure 1.

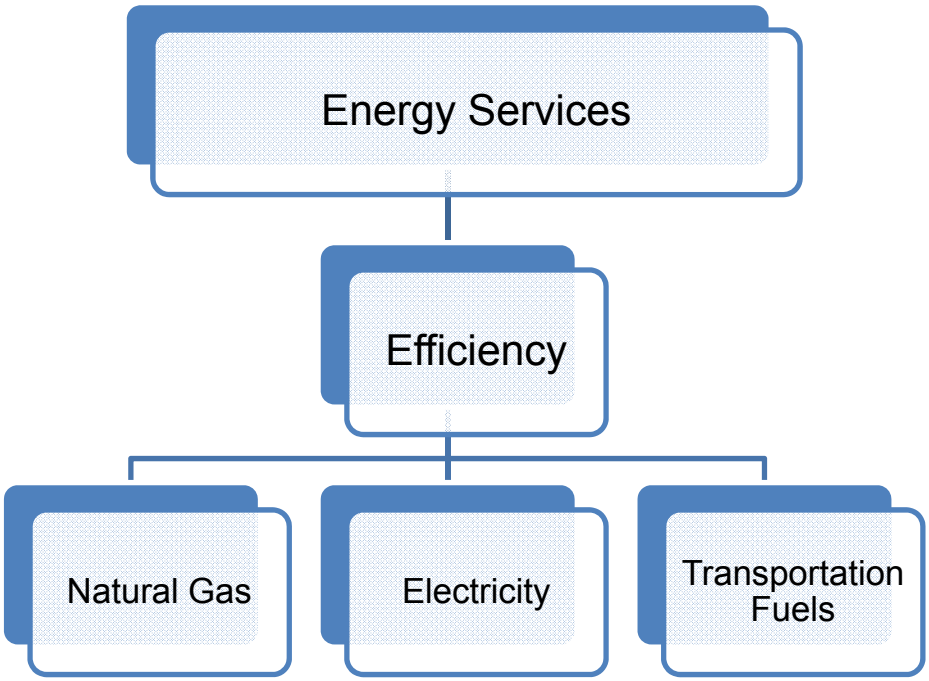

Figure 1 - Major Components of California's Energy System

The services that energy provides—heat, light, transportation, etc—are what matter to consumers. The amount of energy required to provide these services depends on the efficiency with which the energy is used. Improving energy efficiency is the state's highest strategic energy priority, as established in the Loading Order.

In addition to services provided by electricity, natural gas is widely used for space and water heating, cooking, and industrial applications.[11] Transportation fuels are obtained almost exclusively from petroleum. The focus of this paper is on electricity, but the other sectors have been included in Figure 1 as reminder that policies to reduce the use of heat or transportation fuels—promotion of plug-in hybrid vehicles, for example—affect electricity sector plans.[12]

Demand for electric energy services depends on population, economic activity, energy prices, changing technology, and so forth. Official projections of these factors, efficiency improvements,

[11] Propane is often used in rural areas where natural gas is unavailable.
[12] California Energy Demand 2010-2020. The CEC projects that about 4,400 GWh will be used by residential electric vehicles in 2020.

and resulting electricity demand are the responsibility of the CEC and are reported in its demand forecasts.

The CEC recognizes, of course, that projections are uncertain. Changes in demand for energy services depend on projected economic activity, for example. In addition to the economic forecast used as the basis of its 2009 demand forecast, the CEC also considered more optimistic and more pessimistic economic scenarios. In these scenarios, demand for electric energy services increased and decreased about 2% (about 6,000 GWh) respectively.[13]

The Role of Efficiency

CEC forecasts of efficiency improvements and energy savings are based on the effect of *adopted* appliance standards, naturally occurring savings and utility programs. The reference forecasts do not include estimates of additional efficiency savings which might reasonably be expected to occur in the forecast time frame—so-called "uncommitted" or "incremental" efficiency savings—for which an approved plan does not exist. However, the low load scenario does include incremental savings estimates. Since both committed and incremental efficiency savings forecasts influence future demand for electric energy, it is essential that the CEC, CPUC, ARB, CAISO and CTPG ("planning entities") agree on reasonable forecasts—including forecasts of incremental energy savings—so that a maximum degree of stakeholder and public consensus can be developed.

The models used by the CEC to forecast the need for energy services are sophisticated, and input methodology has been standardized. The methodology for forecasting incremental efficiency savings has not. Until all appropriate agencies agree on a reasonable forecast of efficiency savings and a broad consensus is reached among the public on how to incorporate the effects of these uncertain forecasts on the net short, decisions on electricity projects will be subject to more dispute than necessary.

Challenge #1 – Development of broad consensus among stakeholders and the public on reasonable expectations for the improvement in energy efficiency and agreement by CEC, CPUC and ARB.

Electricity Supplies

Figure 2 illustrates the major components of the state's electricity supply. Numerical values and nomenclature shown are based on the CEC demand forecast included in the 2009 IEPR for the year 2020 as modified by RETI's PV projections.[14] Private Supply represents consumer-owned generation used "behind the meter" and not supplied to the consumer by the local utility.[15] Utility Supply represents total sales by all LSEs. Losses—occurring in both transmission and distribution systems—are estimated for utility supplies only.

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[13] Ibid.

[14] As described in the previous net short update, RETI includes estimated "incremental" PV generation in addition to CEC projections. As a result, the values of some components shown in this document differ somewhat from those in the CEC demand forecast. Refer to the Net Short Calculator and Appendix A for details.

[15] For purposes of this paper, "utility" includes non-utility load serving entities. Renewable private supply does not count toward RPS goals under current rules since the RPS targets are based on LSE sales.

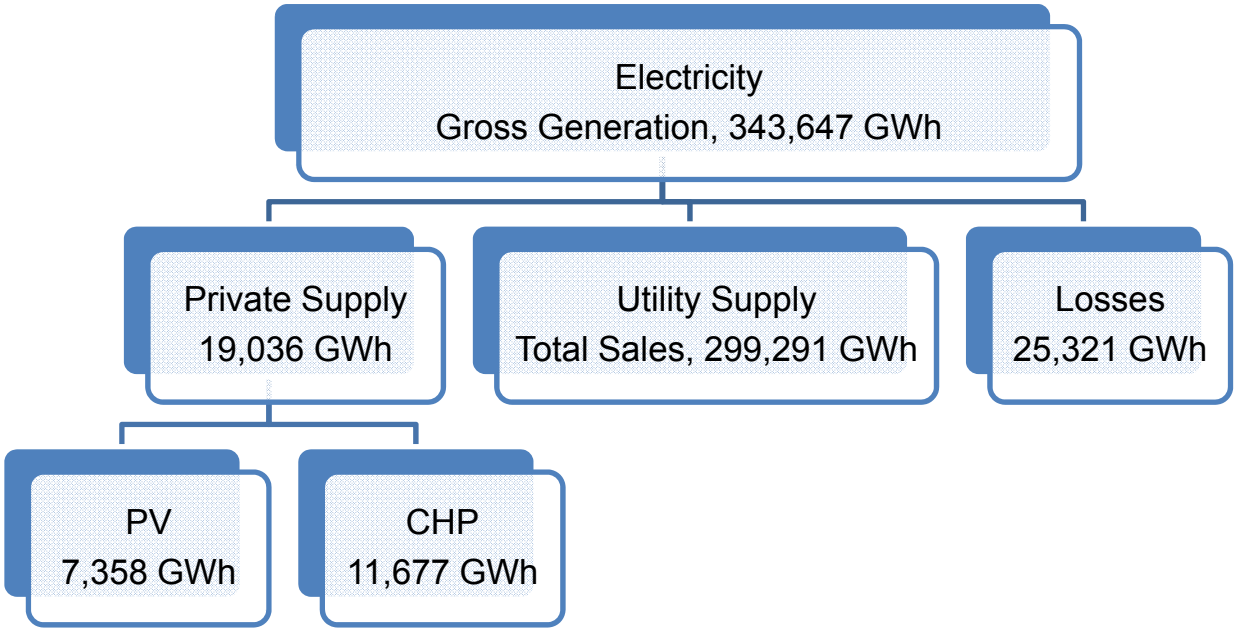

Figure 2 – California Electric Energy Supplies and Losses in 2020 (CEC Forecast)

Also illustrated in Figure 2 are the components of private supply estimated by RETI for 2020, summarized as PV and combined heat and power (CHP).[16] Projected PV generation comes from familiar rooftop solar panels which primarily serves owners' needs.[17] Also shown as potential private supply is "combined heat and power" (CHP). Currently this electrical component is generated primarily from fuel combustion in industrial applications where exhaust heat is used in other processes with high overall efficiency. Fuel cells are emerging as a potential source of CHP, and deployment of this technology could increase significantly if costs are reduced substantially.[18]

Since increasing private supply reduces the need for utility supply, the level of private supply also helps determine the need for expanded transmission capacity and development of generation projects for utility supply. If the recent significant decline in PV prices continues when economic conditions improve then current forecasts may substantially underestimate expected private supply in 2020. Failure of planning entities to build stakeholder consensus on the rate of penetration of PV and CHP private supply and agree on a common forecast will make it more difficult than necessary to reach agreement on the need for proposed generation and transmission projects.

Challenge #2 - Development of broad consensus among stakeholders and the public on reasonable expectations for the penetration of PV and/or CHP and agreement by CEC, CPUC and ARB.

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[16] This document assumes that all non-renewable private supply comes from combined heat and power facilities. The CEC value is used.
[17] A small amount may reach other customers under "net metering" arrangements.
[18] See Combined Heat and Power Market Assessment, ICF Incorporated, October 2009, pages 27 and 28. Energy Commission report: CEC-500-2009-094-D.

Utility Electricity Supplies

Components of utility supply (referred to as "total sales" in the CEC demand forecast) are shown in Figure 3. A fraction of utility supply is used by water agencies for pumping loads and is not subject to RPS requirements. The remainder is sold at retail by load serving entities (LSEs) to consumers. The RPS target is for LSEs to obtain 33% of retail sales from eligible renewable resources by year 2020.

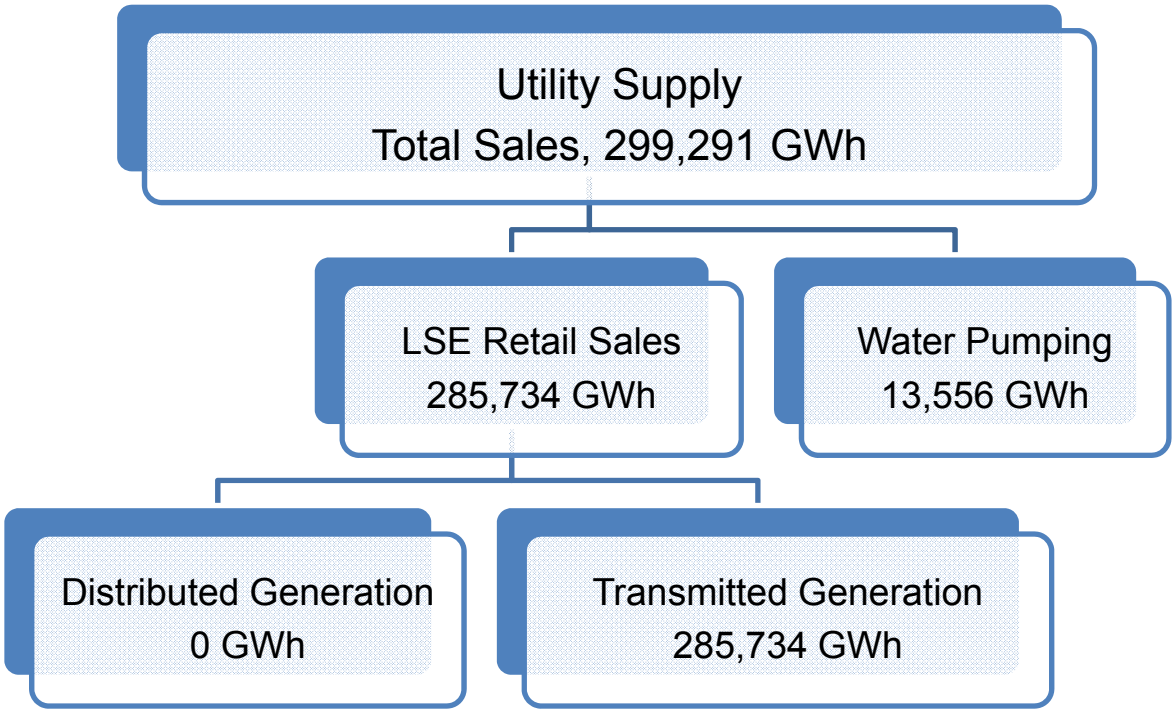

Figure 3 – Components of Utility Electricity Supply

Utility Supply Requiring Transmission

The components of transmitted generation subject to RPS requirements are shown in Figure 4. In the absence of significant distributed generation, transmitted generation is equal to LSE Retail Sales as shown in Figure 3. Satisfying the 33% RPS in 2020 would require a projected total of 94,292 GWh as shown in Figure 4. CEC estimates that 38,174 GWh of RPS eligible renewable energy were on line at the beginning of 2010[19], implying that an additional 56,118

[19] Private communication from CEC staff.

Existing renewables as of 1/1/10 include:

31,272 GWh reported in 2008 Net System Power Report

2,533 GWh IOU renewable online since 2008 NSP

2,116 GWh short-term out of state on lines since 2008 NSP

2,253 GWh POU online since 2008 NSP

GWh must be added by 2020. 3,355 GWh of that is expected to be supplied by miscellaneous renewable energy projects which do not require increases in transmission capacity.

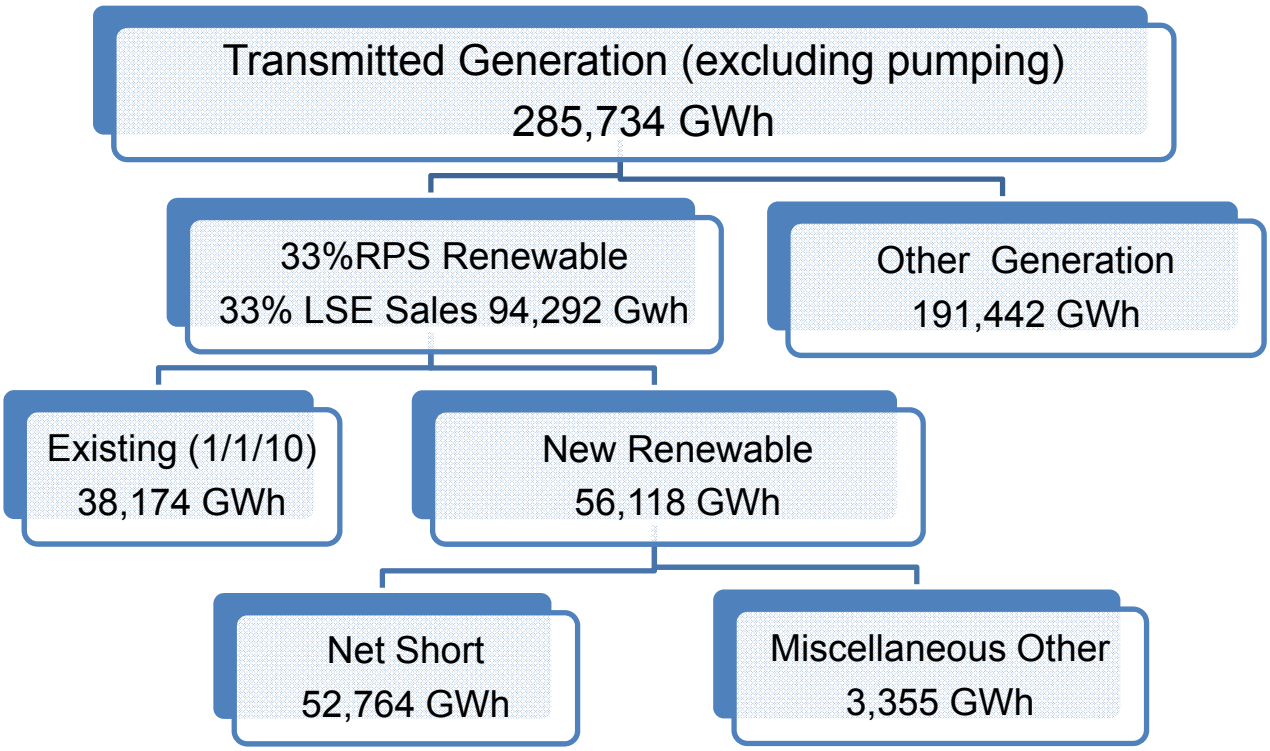

Figure 4 – Components of Transmitted Generation, Excluding Water Pumping Loads

The "Miscellaneous Other" category includes potential distributed RPS-eligible renewable generation components of utility supply. At present, nearly all LSE supplies—including renewable energy—are transmitted through the high voltage electricity grid. When the advent of lower cost PV projects of 20 MW or smaller and occupying sites of about 100 acres or less, the potential exists for substantial development of distributed solar generation located close to urban loads and connected to the grid at lower voltage substations in the electric distribution system. Although distributed generation currently is small, it has the potential to increase substantially.

The distribution system, however, is designed to enable energy from the high voltage transmission system to reach consumers, not to transmit energy in the opposite direction. The highly technical question of how much distributed generation can be connected without compromising safety and reliability has not been fully investigated and resolved.

Challenge #3 - Development of broad consensus among stakeholders and the public on reasonable expectations for distributed generation and agreement by CEC, CAISO and CTPG.

Table 2, taken from the Net Short Calculator, shows all the components of the net short calculation with the values used in the current assessment. Table 3, is a net short calculation

for the low load scenario assumptions. Documentation of the assumptions for both tables is included in the appendix but the assumptions supporting the net short calculation are described briefly here since they are new.

Low Load Scenario Assumptions

Table 3 shows the net short calculation for the low load scenario. The low load scenario is different in three areas: incremental energy efficiency, incremental private CHP and incremental miscellaneous other generation. The incremental energy efficiency has the largest impact with 16,267 GWh. The estimate reflects the medium incremental energy efficiency estimates for IOU's reported in the Energy Commission's February 2010. The low load scenario augments the Energy Commission estimate by assuming that POU's penetration of incremental efficiency will be proportional to the IOU penetration on a per KWh sales basis.

Table 3 further shows an incremental CHP impact of 13,629 GWh. The low load scenario reflects the 2019 base incremental CHP estimate from the October 2009 Energy Commission report prepared by ICF. The low load scenario also adds generation to the Miscellaneous Other Generation category to reflect incremental penetration of producer side of the meter distributed generation. No estimate of expected producer side of the meter distributed generation has been produced by the California energy agencies to date so the number chosen is a place holder pending the provision of a well-founded estimate. The number chosen uses the RETI consensus that private PV and incremental private PV will be 7,358 GWh, and assumes that producer side of the meter DG will be the same amount. Some producer side of the meter DG is already reflected in other generation so once this amount is netted out, an increment of 6,741 GWh is added to other miscellaneous generation.

The net short for the low load scenario is a highly uncertain number. Reasonable estimates of lower and upper bounds on the EE, CHP and producer DG incremental effects have not been promulgated by the agencies so the extent of the uncertainty is not known. However, the estimates provided appear to be within the realm of technical feasibility given the studies produced to date.

Variable	Variable Name	2020 Value GWh (Note 1)
Electric Energy Services	EnergyServices	343,647
Incremental Efficiency	IncEff	0
Gross Generation	GrossGen	343,647
Total Private Supply	TotPrivSupply	19,036
Private PV	PrivPV	3,218
Incremental Private PV	IncPV	4,140
Private CHP	PrivCHP	11,677
Incremental Private CHP	IncCHP	0
Net Losses	Losses	25,321
Utility Supply	UtilSupply	299,291
Water Pumping	PumpLoad	13,556
LSE Retail Sales	RetailSales	285,734
Non-RPS Generation	OtherGen	191,442
Existing Non-RPS Generation (Note 1)	ExistOther	217,745
Decline in Non-RPS Generation	**FreedFossil**	**26,303**
33% RPS Generation	RPSGen	94,292
Existing Renewable Generation (Note 1)	ExistRenew	38,174
New Renewable Generation	NewRenew	56,118
Misc. Other Generation	MiscRenew	3,355
RETI Renewable Net Short	**NetShort**	**52,764**

Table 2 – Components of the Net Short Calculation

Variable	Variable Name	2020 Value GWh (Note 1)
Electric Energy Services	EnergyServices	343,647
Incremental Efficiency	IncEff	16,267
Gross Generation	GrossGen	327,380
Total Private Supply	TotPrivSupply	32,665
Private PV	PrivPV	3,218
Incremental Private PV	IncPV	4,140
Private CHP	PrivCHP	11,677
Incremental Private CHP	IncCHP	13,629
Net Losses	Losses	22,989
Utility Supply	UtilSupply	271,727
Water Pumping	PumpLoad	13,556
LSE Retail Sales	RetailSales	258,170
Non-RPS Generation	OtherGen	172,974
Existing Non-RPS Generation (Note 1)	ExistOther	217,745
Decline in Non-RPS Generation	**FreedFossil**	**44,771**
33% RPS Generation	RPSGen	85,196
Existing Renewable Generation (Note 1)	ExistRenew	38,174
New Renewable Generation	NewRenew	47,022
Misc. Other Generation	MiscRenew	10,096
RETI Renewable Net Short	**NetShort**	**36,926**

Table 3 – Components of the Net Short Calculation Low Load Case

Transmission of Electricity from Non-Renewable Resources

In addition to renewable energy satisfying the RPS, 67% of retail sales are from "other" resources, including hydroelectricity, nuclear, and fossil-fueled generation. The value shown in Figure 4 and Table 2 is a decrease of 26,303 GWh from 2009 levels.[20] A major policy goal of the RPS is to decrease emissions of carbon dioxide from fossil fuel combustion, so presumably this reduction will be made in fossil-fueled generation rather than in nuclear or hydroelectric generation.

Depending on which fossil generators provide less energy, transmission capacity now used for fossil-fueled electricity may be available to transmit renewable energy. For example, currently the state depends on electricity imported from neighboring regions for substantial amounts of energy transmitted to California consumers over the state's transmission system. If this imported fossil energy were replaced by imported RPS eligible renewable energy[21], up to 26,303 GWh of existing state transmission capacity might be available reducing the renewable net short substantially.[22]

However, which fossil-fueled generators will be less relied on in the future is uncertain. For example, the state's Water Quality Control Board has issued a draft policy limiting the amount of water that California power plants can use for "once through" cooling (OTC power plants).[23] Reductions in fossil-fueled generation may therefore come from closure or curtailment of OTC power plants rather than from imports.

Increasing reliance on renewable generators and reducing the use of fossil generators is likely to have significant implications for operation and reliability of the electricity grid. It may be necessary to replace OTC plants with air-cooled generators to provide standby capacity for local reliability, for example. Studies indicate that no insurmountable technical difficulties are likely to arise, but further studies are underway.

Despite this uncertainty, less fossil-fueled electricity will require transmission across the grid, making it likely that at least some of this capacity will be available for transmitting renewable energy. Transmission plans must describe convincingly how this capacity is being used to reduce the need for new facilities.

Challenge #4 - Development of broad consensus among stakeholders and the public on reasonable expectations for displacement of fossil-fueled generation and agreement by CAISO, CPUC, ARB, CEC, and CTPG.

Transmission of Electricity from Renewable Resources

New transmission facilities needed to satisfy the state's renewable energy goals will depend heavily on where the renewable generators will be located. RETI has studied *potential* locations

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[20] LSE other generation in 2009 computed as {gross generation – losses – private supply – water pumping – existing renewable generation}. See 2009 Demand Forecast forms 1.1c and 1.2.

[21] How much out of state renewable energy should be allowed to be used to satisfy the RPS is a controversial issue.

[22] Due to differences in fossil and renewable generation locations and capacity factors, transmission capacity now used by fossil generation **cannot** be assumed to be available and adequate to transmit the same amount of renewable energy.

[23] State Water Resources Control Board, November 23, 2009 draft, Clean Water Act Section 316(b), available at:
http://www.waterboards.ca.gov/water_issues/programs/npdes/docs/cwa316/otcpolicy112309_clean.pdf

in considerable detail.[24] Considerable uncertainty remains, however, about where development will in fact take place. Utilities have signed contracts with individual renewable projects and some projects already have agreements to interconnect with the grid, but not all of these projects will be completed by 2020. The state Desert Renewable Energy Conservation Plan (DRECP) under development may limit development in certain areas. The federal Bureau of Land Management (BLM) also is studying areas for potential development. New areas are being proposed, as well. Plans are underway to increase transmission capacity in neighboring regions to deliver renewable energy to California.

Several years may elapse before renewable energy development patterns are clear. Since major transmission projects have lead times of 7 years or more, however, decisions on needed new transmission facilities must be made in the next year or so if sufficient capacity is to be available by 2020.

As discussed below, uncertainties in renewable energy development patterns—as well as uncertainties in efficiency savings, PV private supply, and so forth—are dealt with by considering various scenarios of future generation patterns, fossil and non-fossil.

Use of Tradable Renewable Energy Credits for RPS Compliance

In December, 2009, the CPUC issued a proposed decision which, if adopted, would allow the use of tradable renewable energy credits (TRECs) for RPS compliance.[25] Discussion of TRECs, their use for RPS compliance, and implications for transmission planning is beyond the scope of this document. However, widespread use of TRECs could change estimates of needed new transmission capacity substantially. Entities involved in transmission planning should monitor the potential development and implementation of TREC policies and adjust plans accordingly in the future.

RETI's Role in Future Energy Planning Activities

As is apparent from the above discussion, a great many factors influence decisions about what new transmission facilities are expected to be needed by 2020 to meet the state's energy goals. These major factors are shown in Table 3:

Factor #	Area	Issues
1	Energy Services	economic and technology changes
2	Efficiency	uncommitted efficiency savings
3	Private Supply	PV and CHP penetration
4	Utility Supply	distributed generation development
5	Renewable Generation	location and quantity of resources developed
6	Other Generation	location and quantity of displaced resources

Table 3 – Major Factors Determining Need for Expanded Transmission Capacity for RPS

Factors 1-4 in Table 3 must be quantified and agreed upon before the net short value can be used for credible transmission planning (see also Table 2.)

[24] RETI Phase 2A Report. An update of data in this report is in progress and should be released in the near future.

[25] Decision Authorizing Use of Renewable Energy Credits for Compliance with the California Renewable Portfolio Standard, Revised Proposed Decision of ALJ Simon, mailed December 23, 2009. Available at: http://docs.cpuc.ca.gov/efile/PD/111679.pdf.

> **Recommendation – Building consensus on appropriate inputs to the net short calculation which have yet to be determined should be given high priority by RETI stakeholders and other transmission planning entities.**

Since the formation of RETI, electricity planning by other entities has accelerated. The California Independent System Operator (CAISO) has launched its Renewable Energy Transmission Planning Process (RETPP). The California Public Utilities Commission (CPUC) is engaged in its Long Term Procurement Planning process (LTPP.) A newly formed California Transmission Planning Group (CTPG) has begun a statewide planning process. The Air Resources Board (ARB) is identifying strategies to reduce greenhouse gas emissions, including increased reliance on renewable energy.

In order to successfully implement state policies, in addition to agreement on inputs to the net short calculation, all planning entities must agree on planning scenarios to be used (Factors 5 & 6 in Table 3.) The need for any particular transmission project cannot be credibly demonstrated if official agencies disagree on the methods and inputs used to evaluate that need. In addition, the broadest possible consensus on assumptions, projections, and scenarios must be developed among stakeholders and the public in order to minimize disagreement over the need for individual projects.

Summary

The RETI net short calculation, using previous methodology, now has an estimated value of 52,764 based on the latest CEC forecasts. A low load scenario has been developed and it yields an estimated net short of 36,926. In addition to uncertainty arising from projected economic growth, agreement must be reached on several other essential inputs before the net short value can be used for renewable transmission planning. In addition, realistic scenarios for future renewable development and declining fossil energy use must be agreed upon in order to develop credible conceptual transmission plans.

> **Recommendation – Building consensus on appropriate inputs to the net short calculation which have yet to be determined should be given high priority by RETI stakeholders and other transmission planning entities.**

The engagement of many other planning entities, in addition to RETI, in renewable transmission planning requires that all must work closely together to ensure emerging plans are based on a common methodology. Although all these entities are represented in RETI, they have their own processes, stakeholder involvement requirements, and so forth. RETI's planning role has therefore changed significantly. For the last two years RETI has provided the major forum for stakeholder involvement in renewable transmission planning discussions. In the future, RETI's role will increasingly involve coordination of planning activities by other entities which affect the need for new transmission projects.

Appendix A
RETI Net Short Calculator – Base Case

Variable	Variable Name	2020 Value GWh (Note 1)	Description (Note 1)
Electric Energy Services	EnergyServices	343,647	Services provided by electricity and electric efficiency. Calculated as gross generation per 2009 demand forecast , Form 1.2, plus "other" LSE sales, Form 1.1c, not included in Form 1.2 (Note 4)
Incremental Efficiency	IncEff	0	Incremental efficiency savings not included in the 2009 demand forecast.
Gross Generation	GrossGen	343,647	Electric generation required to meet load net of incremental efficiency savings.
Total Private Supply	TotPrivSupply	19,036	Behind the meter private generation, assuming none is sold to LSEs via net metering or other arrangements. Components are assumed to be customer-owned PV and CHP.
Private PV	PrivPV	3,218	PV from CEC Form 1.2, not RPS eligible under current rules.
Incremental Private PV	IncPV	4,140	RETI approved increase to CEC value, 2009 net short update. (Note 5) (energy from 3.7 GW @ 0.2 cf)
Private CHP	PrivCHP	11,677	Non-PV self-generation from CEC form 1.2
Incremental Private CHP	IncCHP	0	Potential Increase in non-PV private supply, eg CHP, above CEC value.
Net Losses	Losses	25,321	Net Losses = LossFactor*(GrossGen - TotPrivSupply). LossFactor is calculated from Form 1.2 data.
Utility Supply	UtilSupply	299,291	Gross Generation less losses and private supply
Water Pumping	PumpLoad	13,556	Total Pumping Load from Form 1.1c
LSE Retail Sales	RetailSales	285,734	Utility Supply less Water Pumping
Non-RPS Generation	OtherGen	191,442	67% of LSE retail sales

Existing Non-RPS Generation (Note 1)	ExistOther	217,745	Non-renewable generation on line 1/1/2010, calculated as 2009 LSE sales excluding pumping (Form 1.1c) minus existing renewable generation.
Decline in Non-RPS Generation	**FreedFossil**	**26,303**	**Decrease in non-renewable generation requiring transmission 2010-2020, excluding changes in pumping loads.**
33% RPS Generation	RPSGen	94,292	33% of LSE retail sales
Existing Renewable Generation (Note 1)	ExistRenew	38,174	RPS eligible generation on line 1/1/2010 (CEC staff data). (Note 2)
New Renewable Generation	NewRenew	56,118	New RPS eligible renewable generation required to meet 33% goal.
Misc. Other Generation	MiscRenew	3,355	New RPS eligible renewable generation NOT needing transmission expansion, **including RPS elegible renewable distributed generation** (Note 5) and 33% of "other" LSE sales, Form 1.1c. (Note 4)
RETI Renewable Net Short	**NetShort**	**52,764**	**New RPS eligible renewable generation NEEDING transmission expansion.**

Appendix A
RETI Net Short Calculator Notes – Base Case

Notes
1) All values are 2020 projections except for "existing" resources.
2) Existing renewables as of 1/1/10 include:
31,272 GWh reported in 2008 Net System Power Report
2,533 GWh IOU renewable online since 2008 NSP
2,116 GWh short-term out of state on lines since 2008 NSP
2,253 GWh POU online since 2008 NSP
3) Miscellaneous other renewable generation includes:
1862 GWh Small projects from Phase 1B Report less ocean wave and current projects
876 GWh of utility owned distributed PV (500 MW)
33% of retail sales by "other" LSEs
4) "other" LSEs are:
City of Needles
Mountain Utilities
Pacificorp
Sierra Pacific Power Company
Surprise Valley Electrical Corporation
Trinity Public Utility District
Truckee-Donner Public Utility District
5) Incremental PV is unchanged from 2009 net short update. In addition, 876 GWh (500 MW) is now credited to miscellaneous other generation.

APPENDIX A
Net Short Calculator – Low Load Scenario

RETI Net Short Calculator Low Load Scenario

Color indicates potential for user input.

Variable	Variable Name	2020 Value GWh (Note 1)	Description (Note 1)
Electric Energy Services	EnergyServices	343,647	Services provided by electricity and electric efficiency. Calculated as gross generation per 2009 demand forecast , Form 1.2, plus "other" LSE sales, Form 1.1c, not included in Form 1.2 (Note 4)
Incremental Efficiency	IncEff	16,267	Incremental efficiency savings not included in the 2009 demand forecast.
Gross Generation	GrossGen	327,380	Electric generation required to meet load net of incremental efficiency savings.
Total Private Supply	TotPrivSupply	32,665	Behind the meter private generation, assuming none is sold to LSEs via net metering or other arrangements. Components are assumed to be customer-owned PV and CHP.
Private PV	PrivPV	3,218	PV from CEC Form 1.2, not RPS eligible under current rules.
Incremental Private PV	IncPV	4,140	RETI approved increase to CEC value, 2009 net short update. (Note 5) (energy from 3.7 GW @ 0.2 cf)
Private CHP	PrivCHP	11,677	Non-PV self-generation from CEC form 1.2
Incremental Private CHP	IncCHP	13,629	Potential Increase in non-PV private supply, eg CHP, above CEC value. (Note 6)
Net Losses	Losses	22,989	Net Losses = LossFactor*(GrossGen - TotPrivSupply). LossFactor is calculated from Form 1.2 data.
Utility Supply	UtilSupply	271,727	Gross Generation less losses and private supply

Water Pumping	PumpLoad	13,556	Total Pumping Load from Form 1.1c
LSE Retail Sales	RetailSales	258,170	Utility Supply less Water Pumping
Non-RPS Generation	OtherGen	172,974	67% of LSE retail sales
Existing Non-RPS Generation (Note 1)	ExistOther	217,745	Non-renewable generation on line 1/1/2010, calculated as 2009 LSE sales excluding pumping (Form 1.1c) minus existing renewable generation.
Decline in Non-RPS Generation	**FreedFossil**	**44,771**	**Decrease in non-renewable generation requiring transmission 2010-2020, excluding changes in pumping loads.**
33% RPS Generation	RPSGen	85,196	33% of LSE retail sales
Existing Renewable Generation (Note 1)	ExistRenew	38,174	RPS eligible generation on line 1/1/2010 (CEC staff data). (Note 2)
New Renewable Generation	NewRenew	47,022	New RPS eligible renewable generation required to meet 33% goal.
Misc. Other Generation	MiscRenew	10,096	New RPS eligible renewable generation NOT needing transmission expansion, **including RPS elegible renewable distributed generation** (Notes 5, 7) and 33% of "other" LSE sales, Form 1.1c. (Note 4)
RETI Renewable Net Short	**NetShort**	**36,926**	**New RPS eligible renewable generation NEEDING transmission expansion.**

APPENDIX A
Net Short Calculator Notes – Low Load Scenario

Notes
1) All values are 2020 projections except for "existing" resources.
2) Existing renewables as of 1/1/10 include:
31,272 GWh reported in 2008 Net System Power Report
2,533 GWh IOU renewable online since 2008 NSP
2,116 GWh short-term out of state on lines since 2008 NSP
2,253 GWh POU online since 2008 NSP
3) Miscellaneous other renewable generation includes:
1862 GWh Small projects from Phase 1B Report less ocean wave and current projects
876 GWh of utility owned distributed PV (500 MW)
33% of retail sales by "other" LSEs
4) "other" LSEs are:
City of Needles
Mountain Utilities
Pacificorp
Sierra Pacific Power Company
Surprise Valley Electrical Corporation
Trinity Public Utility District
Truckee-Donner Public Utility District
5) Incremental PV is unchanged from 2+A33009 net short update. In addition, 876 GWh (500 MW) is now credited to miscellaneous other generation.

6) Incremental Private Combined Heat and Power estimate taken from CEC repor CEC-500-2009-094-D, Table C-2, estimate for 2019, and is the sum of direct electricity savings as well as electricity savings from reduced heat load.
7) The low load scenario adds producer side of the meter DG of 6,741 GWh (7,258 GWh (the same as customer side of the meter PV) less an overlap of 617 GWh between other miscellaneous base case and the incremental PV for the low load case). The assumption to make low load miscellaneous generation the same as sum of the private and incremental PV is supported by the following feed-in tariff programs: SMUD's feed in tariff (100 MW limit), AB 32's feed-in tariff for all RPS eligible renewables up to 3 MW (750 MW limit) and the CPUC ALJ's ruling on a standard contract feed-in tariff for all IOU RPS elibigible renewables up to 10 MW (1000 MW limit) sum to a total of 1850 MW which yields about 2/3 of the 6,741 GWh.

Appendix A
CEC Demand Forecast Form 1.1c Summary

Form 1.1c

California Energy Demand 2009-2020 Staff Revised Forecast

Electricity Delivieries to End Users by Agency* (GWH)

Planning Area	Agency	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
PGE Total		105,795	102,236	102,567	103,768	105,255	106,918	108,104	109,282	110,503	111,829	113,080	114,329	115,643
SMUD	Sacramento Municipal Utility District	10,935	10,620	10,629	10,762	10,964	11,164	11,322	11,461	11,586	11,705	11,825	11,949	12,079
SCE Total		99,069	94,985	95,045	95,990	97,258	98,808	99,978	101,202	102,452	103,745	104,987	106,249	107,558
LADWP	Los Angeles Department of Water and Power	24,820	24,029	23,927	24,167	24,574	24,901	25,121	25,330	25,539	25,738	25,944	26,153	26,365
BUGL Total		2,287	2,228	2,223	2,241	2,273	2,297	2,308	2,317	2,326	2,335	2,343	2,352	2,361
PASD	City of Pasadena	1,252	1,217	1,218	1,226	1,235	1,240	1,242	1,246	1,250	1,254	1,257	1,261	1,266
DWR	Department of Water Resources	6,675	8,729	8,729	8,729	8,729	8,729	8,729	8,729	8,729	8,729	8,729	8,729	8,729
SDGE Total		20,623	20,169	20,258	20,488	20,809	21,179	21,457	21,742	21,997	22,266	22,532	22,816	23,102
IID	Imperial Irrigation District	3,291	3,273	3,336	3,419	3,519	3,614	3,696	3,781	3,874	3,971	4,069	4,171	4,280
OTHER Total		1,763	1,763	1,773	1,782	1,791	1,800	1,810	1,819	1,829	1,839	1,849	1,859	1,869
Statewide Total		276,509	269,250	269,705	272,572	276,407	280,650	283,767	286,908	290,084	293,410	296,617	299,869	303,253
Total Pumping Load		11,715	13,331	13,324	13,339	13,358	13,394	13,417	13,440	13,462	13,490	13,511	13,533	13,556
Total Statewide Retail Deliveries excluding pumping		264,794	255,919	256,381	259,233	263,049	267,256	270,350	273,468	276,622	279,920	283,105	286,336	289,697

This table includes retail sales and other deliveries only measured at the customer level; losses and consumption served by self-generation are excluded.

* Includes sales from entities outside of California. Thus, total sales in row 70 are higher than state totals given in Form 1.1b.

Appendix A
CEC Demand Forecast Form 1.2 Summary

Form 1.2 - Statewide
California Energy Demand 2010-2020 Staff Revised Forecast
Net Energy for Load (GWh)

Year	Total Consumption	Net Losses	Gross Generation	Non-PV Self Generation	PV	Total Private Supply	Net Energy for Load
2005	271,192	21,875	293,067	11,440	227	11,667	281,400
2006	280,010	22,566	302,575	11,680	321	12,001	290,575
2007	285,373	23,035	308,408	11,501	440	11,941	296,467
2008	286,771	23,307	310,078	11,373	652	12,025	298,053
2009	280,049	22,598	302,648	11,522	1,040	12,563	290,085
2010	280,843	22,635	303,478	11,574	1,338	12,911	290,567
2011	284,001	22,884	306,885	11,590	1,620	13,210	293,675
2012	288,123	23,219	311,343	11,607	1,901	13,507	297,836
2013	292,649	23,581	316,230	11,615	2,184	13,799	302,431
2014	296,047	23,846	319,893	11,624	2,467	14,091	305,802
2015	299,471	24,111	323,582	11,632	2,750	14,382	309,200
2016	302,929	24,380	327,309	11,641	3,033	14,674	312,635
2017	306,314	24,662	330,977	11,650	3,094	14,744	316,233
2018	309,561	24,935	334,496	11,659	3,134	14,793	319,702
2019	312,854	25,211	338,065	11,668	3,176	14,844	323,221
2020	316,280	25,498	341,778	11,677	3,218	14,896	326,882

Bill Powers

From: Don Kondoleon [Dkondole@energy.state.ca.us]
Sent: Wednesday, January 30, 2008 3:05 PM
To: Bill Powers
Cc: Matthew Layton
Subject: Re: average and peak T&D losses

Bill--- I checked with my staff and unfortunately we do not have a report that documents the loss figures in question. However, they do believe that the 7.5% loss figure on an annual average basis and the 14% loss figure on peak are reasonable assumptions. Sorry I could not be of more help.

Don.

>>> "Bill Powers" <bpowers@powersengineering.com> 1/30/2008 10:57 AM >>>
Hello Don,

Quick question. I just came across this Rocky Mountain Institute slide from an Amory Lovins presentation a few years back. The CEC uses a 7.5% average transmission loss assumption for out-of-state transmission imports for GHG calculation purposes. That is consistent with the slide for average losses. However, the statement is made that EPRI estimates peak losses at 14% and a breakdown is provided for the distribution of these losses through the T&D system.

Does the CEC have a similar report that documents losses on average and at peak in the T&D system?

Thanks,

Bill Powers
Powers Engineering
619-295-2072

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Grid losses increase downstream, so distributed resources cut losses more

- At system peak, EPRI estimates national-average T&D grid losses double from ~7% to ~14%; but where are those losses?
- Murray Davis (Detroit Edison) estimates as typical peak losses 2–3% for T, 6–8% for T+subT, 13–16% for T+subT+D
- Therefore resources sited at/near the down-stream end, i.e. distributed resources, can avoid the biggest grid losses
- They also avoid the biggest grid investments —~US$400–500/kW, not just $100–150/kW
- Save V- and VAR-control equipment too

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California Bulks Up to Provide More Transmission Capacity

Jun 1, 2004 12:00 PM
By Tom Boyko, Western Area Power Administration

The Path 15 upgrade in California represents the first public-private partnership organized to improve a transmission system that has become seriously congested. Pointing out that Path 15 is not the only circuit that has suffered from congestion problems, the Electric Power Research Institute (EPRI; Palo Alto, California, U.S.), estimates that US$100 billion must be spent to upgrade the U.S. electricity grid. At the same time, the Edison Electric Institute (EEI) estimates that $56 billion is required for upgrades over the next nine years. No wonder both the investment community and the electric utility industry are closely watching the project, undertaken by the Western Area Power Administration (Western; Lakewood, Colorado, U.S.). Western has acquired land rights, is managing the construction of the line, will own the line and will retain a 10% share of the new line's capacity. Meanwhile, Pacific Gas & Electric (PG&E San Francisco, California) is financing and building expansions at Los Banos and Gates substations to connect the new line to its system, along with other 230-kV and 115-kV reinforcements north of Midway. Initially, PG&E will receive 18% of the new transmission capacity. Trans-Elect (Reston, Virginia, U.S.) also will invest in the project by providing the remaining financing for the line, entitling it to an initial share of 72% of the new capacity. Final capacity ownership for the two companies will be based on their percentage of project costs, with capacity available to all transmission system users.

The new line will be in the middle of the California ISO's Control Area, with all investing parties turning over operational control to the ISO. The organization of this partnership among private and public entities may serve as a model for future projects as power providers begin their own projects for upgrading aging transmission infrastructure to avoid repeats of the Northeast blackouts that affected more than 50 million people.

Recapping the California Problem

When the lights went out in Northern California in 2000-2001, a long-standing transmission bottleneck received national attention. A contributing factor to the crisis was a transmission constraint in Central California known as Path 15, where three 500-kV lines linking northern and southern California narrowed to two lines for 84 miles (135 km) through the Central Valley. The corridor's lack of transfer capacity hampered efforts to move available generation north from southern California and the desert southwest. To alleviate this constraint, the Department of Energy (DOE) directed Western in May 2001 to explore a Path 15 upgrade. The result was a public-private partnership among Western, Trans-Elect Inc. (the first independent transmission company in the United States) and PG&E, one of three California-based investor-owned utilities. The partnership was charged with the responsibility of constructing a new 84-mile 500-kV line

and for modifying substations at both ends of the new segment. Estimated cost for the project was $306 million.

On Sept. 15, 2003, Trans-Elect's New Transmission Development Company provided Western with the necessary funds to start construction, using Maslonka & Associates (M&A Mesa, Arizona, U.S.) as the line construction contractor.

The upgrade will increase Path 15's south-to-north capacity from 3900 MW to 5400 MW, significantly reducing electricity costs with savings estimated at $100 million annually under normal conditions and more than $300 million during a dry year when Path 15 helps to mitigate lack of hydro in Northern California. The ISO calculates these savings can result in a payoff of the project in four years.

In the 1980s, a Path 15 upgrade was considered for a 500-kV line linking California with the Northwest, as part of the California-Oregon Transmission Project. Due to various regulatory issues, the line was never built. A decade later, increased demand and supply constraints pointed to the need to revisit the upgrade.

By late 1998, load growth had become a significant factor for grid operators, who were prevented from moving power across the congested Path 15. The congestion hit hard in 2000 and 2001 when scarce generation forced the ISO to declare stage-three emergencies, indicating reserves were so low that rolling blackouts were imminent and resulting in several days of rotating outages of firm customer load. The emergencies extended into the winter with threats of outages continuing. Between Sept. 1, 1999, and Dec. 31, 2000, consumers spent an additional $221.7 million in energy costs due to constraints on Path 15.

To address the project mandated by DOE, Western advertised in the Federal Register to determine if investors were interested in financing the upgrades. In June 2002, the Federal Energy Regulatory Commission (FERC) accepted the terms of a letter agreement among Western, Trans-Elect and PG&E, which provided $1.5 million in initial funding from Trans-Elect and outlined the overall project terms and conditions. In December, the project participants signed a Construction and Coordination Agreement, which spelled out project terms and conditions in more detail. Trans-Elect provided an additional $8.5 million to Western in initial funding, followed by construction funding in September 2003.

PG&E performed the Path 15 rating studies using the rating process of the Western Electric Coordinating Council (WECC), which coordinates and promotes system reliability in 14 Western states, two Canadian provinces and portions of one Mexican state. Under the WECC process, PG&E established a group to review and comment on its studies to ensure that any impacts of the proposed upgrade were adequately addressed. Based on the studies, Path 15 received an accepted rating of 5400 MW, south to north, and 3400 MW, north to south. The studies showed the upgrade also will increase the simultaneous import capabilities into the Pacific Northwest during winter and will not affect the operation of other WECC paths at their respective ratings.

Environmental Issues

The Path 15 Upgrade Project is in the foothills on the west side of the San Joaquin Valley in California's Central Valley. The new 500-kV line between Los Banos and Gates substations is being constructed west of the existing Los Banos-Gates and Los Banos-Midway 500-kV lines, which occupy a common corridor near Interstate 5, selected to minimize environmental impact. The separation of the two rights-of-way is about 2000 ft (610 m). Western acquired the necessary

rights-of-way for the transmission line easement and an additional 149 miles (240 km) of access road easements, which were required for project construction. The right-of-way is 200 ft (61 m) wide and vertical ground clearance is 35 ft (10.6 m).

Much of the corridor is dry rangeland used for stock grazing. Because the area also is home to diverse wildlife, plant life and historical and cultural resources, measures were taken to lessen environmental impacts. Environmental analyses in compliance with the National Environmental Policy Act concluded the upgrade would pose no significant, adverse environmental problems. The California Public Utilities Commission (PUC) adopted a Final Environmental Impact Review, which found the proposed corridor west of Interstate 5 as the environmentally superior alternative. In addition, Western's administrator signed a Mitigation Action Plan, which outlines measures designed to reduce adverse environmental impacts. The U.S. Fish and Wildlife Service issued a biological opinion, and Western obtained other necessary permits. Western and other state and federal agencies also signed a programmatic agreement that covers treatment of historical and cultural resources and Native American cultural sites, including burial sites.

As a result of pre-construction environmental surveying, engineers modified the project design to minimize the impact on endangered species and existing farmland. For example, they chose to use steel poles in some areas because they could accommodate anti-perch devices so that raptors would not land on crossarms and contaminate insulators, or hunt down other protected species. Anti-perch devices, made of black polyethylene with UV stabilizer and cone-shaped to prevent raptors from roosting, are designed for installation on crossarms using stainless-steel straps.

Other design modifications could be made to address any significant findings during ongoing paleontological, biological, archaeological and Native American cultural monitoring, which continues throughout the construction of the line. Modifications could include moving roads, shifting structures or re-clearing areas for biological or cultural resources. For instance, before construction started, an access road was moved to avoid sensitive plant areas. A significant effort was expended on tracking and protecting endangered species, such as kit foxes and burrowing owls.

Design and Construction

To design the project, Western's engineers used some of the most technologically advanced tools available, including topographic data of the corridor provided by the Light Detection and Ranging system (LIDAR), which uses a laser beam onboard an aircraft to measure elevation and ground coordinates. This information can be downloaded and used with the Power Line Systems' Computer-Aided Design and Drawings software (PLS-CADD). Using this software, engineers selected the best route and structure locations, generating detailed plan and profile drawings in AutoCad. Maslonka and Associates, the contractor, had access to these drawings over the Internet via a satellite link.

The new line will consist of a single 500-kV circuit, with triple-bundled 1590 kcmil, 45/7 Lapwing ACSR arranged in triangular configuration with 18-inch (45.7-cm) spacing between subconductors. The largest conductor that could be accommodated by the lattice tower structures was selected.

The design also includes spacer dampeners attached to the conductors and vibration dampeners for OHGW. Orange marker balls 36 inches (91.4 mm) in diameter are used at line crossings. In order to make the line more visible to federally protected California Condors, UV-stabilized and

phosphorescent flapper-type line markers are used on the OHGW. Three V-shaped insulator strings support the conductors and maintain electrical design clearance between conductors and towers. Each leg of the insulator string contains 32 ball-and-socket fog-type porcelain insulators, 18 ft (5.5 m) long. Deadend towers have fog-type porcelain, double-horizontal insulator strings about 25 ft (7.6 m) long. Insulator assemblies are similar to those used on the California-Oregon Transmission Project, enabling maintenance crews to use the same equipment and tools for barehand and hot line work.

The groundwire assembly, which includes two 0.5-inch-diameter, high-strength steel, seven-strand ground wires, will protect the conductors from direct lightning strikes. The line will use 246 self-supporting, galvanized lattice steel towers and 98 steel pole structures, averaging four structures per mile. Lattice structures, weighing from 10 to 70 tons, vary in height from 100 to 160 ft (30.5 to 48.8 m). The steel poles, weighing from 20 to 75 tons, vary in height from 127 to 207 ft (36.6 to 63 m).

Almost half of the towers will be installed by Erickson Air-Crane to provide an efficient and economical way to construct the lattice towers, which are assembled in three pieces. The base section, or tower legs, is constructed in a conventional manner by ground crews and set onto the concrete footings. Guide brackets on each top corner of the leg section help guide the bottom of the body into place when flown in and, later, bolted by linemen. The remaining top, or bridge piece, is set by helicopter and bolted. Although the Air-Crane has a high per-hour cost, the expense is offset by the fact that each section can be set in about a minute, plus ferry time to and from the assembly area or fly yard. Because fly yards are on the structure right-of-way, the average time from fly yard to structure location is about five minutes. The Air-Crane helicopter, developed initially for the military, is now in use worldwide after having been remanufactured from military surplus status to civilian specs and modified for heavy-lift construction, logging and fire-tanker operations.

PG&E's Substation Modifications

PG&E, which is responsible for the project's substation and 230-kV transmission line work, awarded two contracts to Burns & McDonnell (Kansas City, Missouri, U.S.) for substation modifications and 230-kV shunt capacitor work. Substation modifications include: installing two new 500-kV circuit breakers at Gates Substation and modifying Gates' 500-kV bus from a ring bus to a breaker-and-a-half arrangement; installing 250 MVARs of 230-kV shunt capacitors at Los Banos Substation; installing 250 MVARs of 230-kV shunt capacitors at Gates Substation; reinforcing sections of 230-kV and 115-kV lines north of Midway.

The breaker-and-a-half design is considered to be the industry-standard design for the number of lines and transformer banks terminating in a 500-kV bus. Its design is consistent with ISO operating practices and is more reliable because it allows for easier maintenance and more operating flexibility. The reinforcement work of the 230-kV and 115-kV lines north of Midway includes raising some of the 230-kV towers to accommodate an increase in conductor sag. PG&E also will install current-limiting reactors to limit the flow on the parallel system.

Tom Boyko is project manager for Western's Path 15 Upgrade Project and works out of Western's Sierra Nevada Regional office in Folsom, California. He holds a degree in electrical and electronics engineering from North Dakota State University.
boyko@wapa.gov

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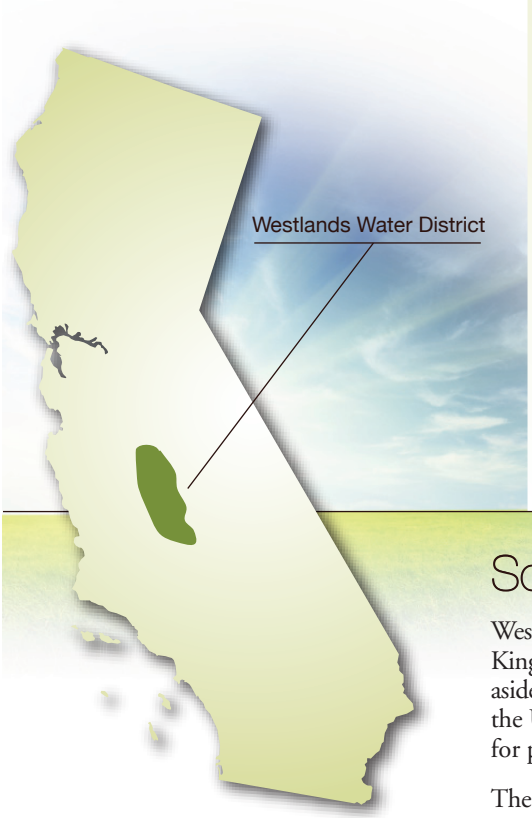
CENTRAL CALIFORNIA RENEWABLE MASTER PLAN



Putting California At The Forefront Of Global Clean Energy Production & Economic Opportunity

- Approximately 30,000 acres of disturbed and contiguous farmland undergoing study as the Westlands Clean Renewable Energy Zone (CREZ) by the Renewable Transmission Initiative (RETI)
- Successful master planning sets the stage for California to meet its near and long term goals for the RPS, while providing certainty to future renewable development
- The broader Westlands area has an estimated potential of accommodating up to 5 GWs or more of renewable power by 2020
- Proximity to existing substations and transmission lines. The Westlands study area is strategically placed near a future planned foundation line corridor that will be designed to connect the different renewable zones in California.
- The Central California Renewable Master Plan is a more environmentally superior alternative to permit for large scale solar than constructing in protected lands in remote desert areas
- Allows large scale solar energy to be produced within California

Solution: The Central California Renewable Master Plan

Westlands Water District (Westlands) covers over 600,000 acres of farmland in western Fresno and Kings Counties. Due to salinity contamination issues, a portion of this disturbed land has been set aside for retirement and will be taken out of production under an agreement between Westlands and the US Department of Interior. This situation positions the Central California Renewable Master Plan for permitting success, solving permitting challenges that are hindering most California projects.

The Central California Renewable Master Plan includes approximately 30,000 acres of disturbed land for renewable development. This acreage is within close proximity to existing transmission corridors and substations, as well as future planned foundation line corridors. The master planning of thousands of acres for utility scale solar generation is a relatively new concept for energy developers but the environmental community and California policymakers are starting to see its benefits. This type of planning better aligns the generation and transmission planning for renewables, resulting in more efficiently developed projects with a better chance for long-term success.

Garnering Major Environmental Support

The Central California Renewable Master Plan is undergoing study as a CREZ in the RETI Phase 2A updates. Westlands and the Anthem Group are working with environmental groups to identify the Westlands study area as a critical renewable energy zone in order to meet California's renewable goals.

A Solution For Today… And Tomorrow

The far-reaching benefits of this project enables California to set up a process for planning transmission system upgrades and new corridors that will create billions in economic development for California. The template laid out in the Central California Renewable Master Plan provides regulatory and permitting confidence for developers and utilities to orderly construct transmission and generation over a 10-year horizon to meet the 33% by 2020 RPS goal.

Linking California To A Greener Future And Economic Vitality

Led by the Anthem Group, the Central California Renewable Master Plan represents the most viable opportunity for California to advance its renewable energy goals. Over a 20-year horizon the potential estimates of total project investment for the 5 GW solar plant could reach well over $10 billion and will provide California with a much-needed economic boost.

CENTRAL CALIFORNIA RENEWABLE MASTER PLAN

Please contact the Anthem Group at (916) 709-9289, dan.anthem@gmail.com or PO Box 582844 Elk Grove, CA 95758-0051 for questions or inquiries on the this project.

Restoration Ecology
THE JOURNAL OF THE SOCIETY FOR ECOLOGICAL RESTORATION INTERNATIONAL

RESEARCH ARTICLE

How Much Compensation is Enough? A Framework for Incorporating Uncertainty and Time Discounting When Calculating Offset Ratios for Impacted Habitat

Atte Moilanen,[1,2] Astrid J. A. van Teeffelen,[1,3] Yakov Ben-Haim,[4] and Simon Ferrier[5]

Abstract

Biodiversity offset areas may compensate for ecological damage caused by human activity elsewhere. One way of determining the offset ratio, or the compensation area needed, is to divide the present conservation value of the development site by the predicted future conservation value of a compensation area of the same size. Matching mean expected utility in this way is deficient because it ignores uncertainty and time lags in the growth of conservation value in compensation areas. Instead, we propose an uncertainty analytic framework for calculating what we call robustly fair offset ratios, which guarantee a high enough probability of the exchange producing at least as much conservation value in the offset areas than is lost from the development site. In particular, we analyze how the fair offset ratio is influenced by uncertainty in the effectiveness of restoration action, correlation between success of different compensation areas, and time discounting. We find that very high offset ratios may be needed to guarantee a robustly fair exchange, compared to simply matching mean expected utilities. These results demonstrate that considerations of uncertainty, correlated success/failure, and time discounting should be included in the determination of the offset ratio to avoid a significant risk that the exchange is unfavorable for conservation in the long run. This is essential because the immediate loss is certain, whereas future gain is uncertain. The proposed framework is also applicable to the case when offset areas already hold conservation value and do not require restoration action, in which case uncertainty about the conservation outcome will be lower.

Key words: habitat banking, habitat equivalency analysis, information-gap decision theory, mitigation, no net loss principle, offsets, strong sustainability, time discounting, uncertainty analysis.

Introduction

Several countries have adopted policy to regulate the impact of economic development on natural habitats. After estimating the expected damage that a particular development project will do to existing habitat and associated species, a hierarchy of measures can be employed to alleviate the impact (Cuperus et al. 2001; ten Kate et al. 2004). The first step in this hierarchy aims at avoidance of the impact, e.g., by looking for alternative locations for development, where impact will be less severe. Once the development location is chosen, the second step concerns minimizing the impact. In the European context, this step is often referred to as mitigation, whereas in North America, the term mitigation often refers to the third step, the use of compensation measures for unavoidable damage to natural areas (Race & Fonseca 1996; ten Kate et al. 2004). Here, we use the term biodiversity offsets to indicate ecological compensation for unavoidable damage.

Biodiversity offsets involve the designation of compensation areas, which either hold significant conservation value already or where habitat creation, recreation, or restoration practices are carried out in order to balance for biodiversity loss elsewhere. Typically, loss is caused by direct anthropogenic action (urban expansion, etc.), but offsets could also be used to compensate for the slow degradation of biodiversity from present reserve areas (Sinclair et al. 1995). As ten Kate et al. (2004) emphasize in their review, quantitative guidelines for determining offset ratios and types are generally lacking. Typically, rules of thumb are used to describe offset requirements in terms of the location and habitat type; compensation areas near the development site and of a similar habitat type are preferred. Although the size of the affected areas is a quantitative measure, determining the conservation value of habitat remains difficult (ten Kate et al. 2004).

A similar concept, No Net Loss (NNL), has been developed for wetlands under the Fisheries Act in Canada and the Clean Water Act in the United States. Under these regulations, permits for development often require offsets

[1] Department of Biological and Environmental Sciences, University of Helsinki, PO Box 65, FI-00014, Finland
[2] Address correspondence to A. Moilanen, email atte.moilanen@helsinki.fi
[3] Present address: Department of Environmental Sciences, Wageningen University, PO Box 47, Wageningen, NL-6700AA, The Netherlands
[4] Faculty of Mechanical Engineering, Technion—Israel Institute of Technology, Haifa 32000, Israel
[5] New South Wales Department of Environment and Climate Change, PO Box 402, Armidale, NSW 2350, Australia

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doi: 10.1111/j.1526-100X.2008.00382.x

to compensate for damaged wetlands. Harper and Quigley (2005) evaluate this approach for Canada (Harper & Quigley 2005; Quigley & Harper 2006*a*, 2006*b*). Quigley & Harper (2006*b*) report that although compensation requirements did determine required offset ratios to be on average 6.8:1 (area gained: area lost), the mean offset ratio that was actually implemented was only 1.5:1, resulting in 10 out of 16 cases not reaching NNL in terms of habitat productivity. Poor compliance to offset agreements was also found to be a problem in Australia by Gibbons and Lindenmayer (2007). The principle of NNL is similar to the concept of strong sustainability in capital theory, which requires that each form of capital, such as conservation value, is kept constant (Cowdy & Carbonell, 1999; Figge & Hahn 2004). A related concept, weak sustainability, allows that different forms of capital can be substituted for each other (Figge & Hahn 2004).

Habitat banking and Habitat Equivalency Analysis (HEA) are yet another two concepts used in the context of habitat compensation measures. Habitat banking, also referred to as "mitigation banking" or "conservation banking," aims at conservation practices which generate "biodiversity credits" that can be traded for later habitat destruction elsewhere by development practices (Bruggeman et al. 2005; Morris et al. 2006). An explicit feature of banking is that credits are generated before damage is undertaken. In contrast, with offsets, damage and credits are generated at best simultaneously. Due to inevitable delays in the growth of conservation value in restoration areas, credits can be realized after a substantial time delay (Morris et al. 2006).

HEA aims to compensate injured natural resources and has, in particular, been applied to coastal and marine habitats (National Oceanic and Atmospheric Administration 2000). Although HEA is widely applied in practice (particularly in the United States), very little has been published in peer-reviewed literature (Race & Fonseca 1996; Dunford et al. 2004). HEA involves quantitative measures to determine the amount of compensation required, potentially accounting for time delays in the process. Dunford et al. (2004) provide a thorough demonstration of the use of HEA in the context of oil spills. Framed in the context of conservation banking, Bruggeman et al. (2005) extended the concept of HEA to terrestrial habitats and coined the term Landscape Equivalency Analysis. They incorporate spatial and population genetic aspects quantitatively into the valuation of habitats and species.

In this study, we are interested in determining the offset ratio needed to achieve a fair exchange of areas. Fair could be defined in many ways. Most simply, one could use a criterion we call "matching mean expected utilities"; utility that is gained (eventually) from the compensation areas is estimated to exactly compensate for the immediate loss of utility from the development site. This criterion is deficient in that it ignores the time lag before the full value of compensation areas is realized, as well as uncertainty in the extent to which the expected conservation value at the compensation areas will be realized (Hilderbrand et al. 2005). Heuristically, matching mean expected utilities is like making a zero interest rate (biodiversity) loan to someone who is known to be unreliable and might pay back decades later.

We compare matching mean expected utility to a strategy that we call robustly fair offsets. We specify that compensation should be fair in the sense that net loss of conservation value is unlikely even when various uncertainties are accounted for. We investigate at a theoretical level what influence the following components have on the estimate of a fair offset ratio: (1) uncertainty in the amount of compensation gained; (2) correlation between (restoration) success of different compensation areas; and (3) time discounting. We develop a framework for the calculation of robustly fair offsets. Using a mathematically simple example, we demonstrate that assumptions about these components make a huge difference for the amount of compensation (offset ratio) that should be perceived as adequate.

Methods

The Conceptual Framework of Robustly Fair Offsets

Our goal of offsetting is consistent with NNL in the sense that present loss is compensated by future gains, accounting for uncertainty and time lags in the development of these gains. We specify that the probability of incurring net loss must be small, thereby ensuring what we call "robustly fair offsets." The uncertainty is a critical component when the aim is to avoid net loss due to unfavorable growth of conservation value at the restoration areas.

We assume three components of uncertainty. (1) Future value could be less than estimated, which could, e.g., represent the case that an area of forest develops fewer nesting holes than expected or that forest understory develops a community which is less species rich than expected. Outcome could be uncertain even when it is practically immediate, e.g., if compensation sites do not require restoration but the areas are poorly surveyed so that what is gained by the exchange is not accurately known. (2) Some feature of conservation value might completely fail to be established, e.g., a focal species may fail to colonize the area. (3) We also allow for the possibility that success and failure could be correlated between different restoration areas. The uncertainties in our analysis are most relevant where restoration action is applied at compensation areas. However, the proposed framework is equally applicable when compensation areas are such that they already hold substantial conservation value and some form of protection is applied rather than restoration action. In this case, uncertainties are smaller (or even zero), but the structure of the proposed calculations need not be changed.

We account for uncertainty by adopting a decision-theoretic approach to the calculation of offsets. If statistical models are available for the components above, one could use a statistical approach for identifying an offset

ratio, which has, e.g., less than 5% chance of resulting in net loss. However, our formulation includes parameters, such as long-term success of restoration effort, for which it may be difficult to obtain reliable distributional information. In such a case, information-gap decision theory (Ben-Haim 2006; hereafter info-gap theory), which we employ here, provides a straightforward way of analyzing the influence of uncertainty on the offset ratio.

Time discounting (Carpenter et al. 2007) of the offset ratio is included because it is not fair to compensate immediate loss by hypothetical distant future gain. Presumably, the conversion of the development site would produce a relatively immediate economic return in the order of some percents per year. This revenue could plausibly be used for further environmentally harmful activity either directly or indirectly. On the other hand, conservation benefits arising from restoration effort may take a very long time to materialize fully, e.g., if one needs to wait for forest to grow. Consequently, we find it reasonable that the offset ratio should be calculated as a time-discounted weighted average across the planning frame. Omitting time discounting could place nature conservation efforts at an overall disadvantage.

These components have been noted in prior work: The outcome of restoration is often different from expected, for instance, due to existence of alternative equilibria and differences in ecological dynamics between degraded and less-impacted systems (Zedler & Callaway 1999; Folke et al. 2004; Suding et al. 2004; Hilderbrand et al. 2005). Following restoration, ecosystems can recover into different states from the same initial condition (Folke et al. 2004). Restoration action can fail despite the correct management action if, for instance, rainfall does not occur (Vesk & Dorrough 2006). Several authors note that there is uncertainty associated with the expected outcome of restoration (Cuperus et al. 2001; Bruggeman et al. 2005; Morris et al. 2006; Gibbons & Lindenmayer 2007) but do not explicitly account for it in their analyses. Keagy et al. (2005) investigate the feasibility of compensation for maintaining overall population abundance in the study area, when the compensation areas are of inferior quality compared to the lost habitat. Gibbons and Lindenmayer (2007) conclude that offsets will only contribute to NNL if (1) clearing is restricted to vegetation that is simplified enough so that its functions can be restored elsewhere; (2) any temporary loss in habitat between clearing and maturation of an offset does not represent significant risk to a species, population, or ecosystem process; and (3) offsets are substantial enough and they are complied to. HEA explicitly includes time discounting as an option (Dunford et al. 2004; Bruggeman et al. 2005). Morris et al. (2006) and Roach and Wade (2006) both mention that there is a time lag between impact and compensation, although they do not present methods that explicitly take that into account in analysis. Here we combine all these factors together into the same quantitative theoretical analysis.

Evaluating Offset Solutions Using an Uncertainty-Analytic Approach

We use info-gap theory (Ben-Haim 2006) to analyze the consequences of uncertainty for establishing a fair offset ratio. The main components of the info-gap theory are the goal (performance aspiration), the performance function, the nominal model, the uncertainty model, and the robustness function.

Our goal is to robustly achieve NNL. The nominal model is our best estimate for the expected conservation value in the development area and compensation areas (thick lines in Fig. 1). We indicate nominal models by $\tilde{V}_0(t)$ and $\tilde{V}_i(t)$ for conservation value at time t at the development area and compensation area i, respectively. The nominal model represents our best understanding of how conservation value will change in these areas over time. However, this information may be quite uncertain, which is modeled by the second central component of info-gap analysis, the uncertainty model (thin lines in Fig. 1). Note that instead of staying stable, conservation value at the development site could be declining, which would lead to smaller offset ratios.

The info-gap uncertainty model does not simply place bounds around the nominal estimate, as it might appear from Figure 1 because worst-case bounds are at best poorly known. Rather, the robustness of solution candidates are analyzed in terms of an uncertainty parameter, the horizon of uncertainty α. When this parameter is zero, it indicates full confidence in our nominal model and the nominal model is accepted as the true model. Higher values for α indicate less confidence in the

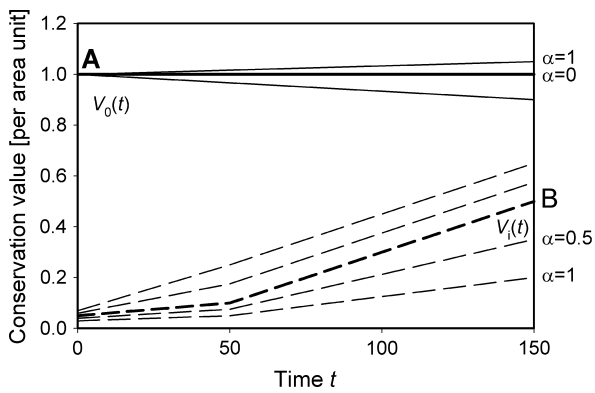

Figure 1. The assumed per unit area change in conservation value at the development area (thick solid line) and at the restoration areas (thick dashed line). Thin lines represent uncertainty bounds around these estimates; the relative uncertainty about the growth of conservation value at the restoration area is in our example higher compared to uncertainty about maintenance of value at the development site. The width of the uncertainty bounds would depend on the info-gap horizon of uncertainty parameter, α. When α is zero, the estimate (thick line) is taken as certain. With increasing α, the range of values possible for conservation value widens. Points A and B are used when calculating a naïve offset ratio based on mean expected value. Note that the conservation value of the development site is our estimate of what it would be if it was not developed. We assume that as a consequence of development, all conservation value is lost.

nominal model: the true model is somewhere within an expanding bound around the nominal model. In our example of Figure 1, the uncertainty model is represented by the thin lines around the nominal model. When $\alpha = 0$, the thick line is taken as the truth, and increasing α implies expanding bounds of possible outcome. Importantly, different areas and restoration actions could have different nominal estimates as well as different levels of uncertainty (often called error weights). For example, smallest error weights could be associated with a presently high-quality area that has been well surveyed. A relatively higher error would go for an area that is apparently valuable but is poorly surveyed. Highest error weights would be associated with areas where there is substantial lack of knowledge concerning the growth of conservation value there, e.g., as a consequence of trying out a completely new restoration technique. Technically, when evaluating a solution at any given level of α, the solution is evaluated according to the most adverse choice of the model inside the uncertainty bounds. However, since the horizon of uncertainty, α, is unknown, a solution is evaluated according to the greatest α up to which that solution yields adequate outcomes.

The aim of our uncertainty analytic approach is to identify solutions that are robust in the sense that they achieve our performance aspiration even when allowing for high uncertainty. In the typical info-gap formulation, the robustness of a solution, α^*, is the highest α at which it is guaranteed to meet the performance target (Fig. 2a). A solution is not robust if it may fail to achieve the goal even at low α, indicating that a small deviation from expected restoration outcome might miss the target of NNL.

Each offset candidate solution would be examined in terms of its performance under increasing uncertainty. This is illustrated in Figure 2. Assuming that offset candidates A, B, and C have equal cost, then A is the best option because it achieves goals while allowing for highest uncertainty (Fig. 2a). Candidate C is the second best option assuming nominal models are correct. However, candidate B is more robust to increasing uncertainty than C.

The robust optimal solution is the one solution that achieves the planners specified goals while allowing for highest possible errors in the nominal models. If only a few scenarios need to be compared, then solution performance and robustness can be evaluated for all candidates. If, however, the robust optimal solution needs to be identified from a large set of options (such as selecting 100 out of 1,000 sites), then some optimization method is needed. Below, we calculate the offset ratio that is sufficient for guaranteeing NNL while accounting for the modeled uncertainties (Fig. 2b).

A Simple Example of the Method

We illustrate the proposed method for the simple case where one unit area of land with relatively high conservation value is offset by a number of units of less valuable land that is restored. In this example, conservation value is treated as a one-dimensional construct. Table 1 gives a summary of symbols used in the equations.

Assuming that all conservation value of the high-quality development area will be lost following the land exchange, a naive solution using matching of mean expected utility for the offset ratio is as follows:

$$N_{\text{simple}} = \frac{\tilde{V}_0(0)}{\tilde{V}_i(t_p)}, \tag{1}$$

where $\tilde{V}_0(0)$ is the best estimate for the conservation value of the development area presently (at time 0) and $\tilde{V}_i(t_p)$ is the best estimate for the final conservation value of the restoration area at the end of the planning period at time t_p. This is the ratio A/B in Figure 1. N_{simple} units of

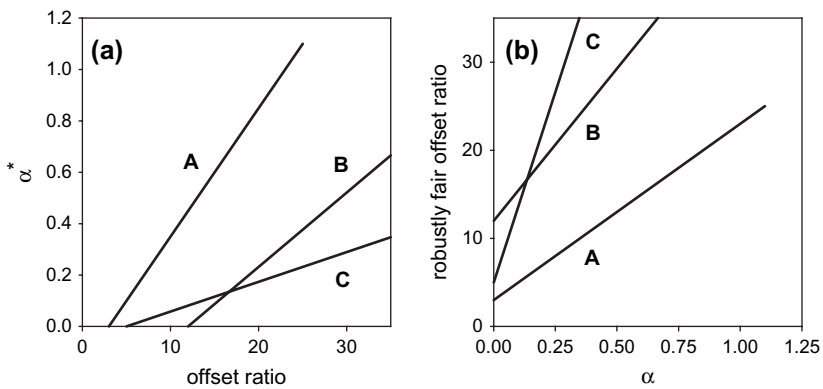

Figure 2. An illustration of how offset solutions would be compared in the info-gap approach. Panel (a) is the typical info-gap representation, in which solutions are graphed in terms of the level of uncertainty they can allow while still guaranteeing the performance goal (NNL). Panel (b) shows the offset ratio needed to guarantee NNL at given level of uncertainty. Each line is for one candidate solution, when uncertainty, α, increases. Of the three candidates, solution A is always best because it produces highest conservation value. Candidate C is better than B with low uncertainty, but with high uncertainty, B guarantees better outcome. Preference between B and C would depend of the level of confidence required for the solution. These curves can be graphed in two alternative ways.

Table 1. Explanation of symbols used.

t_p	Length of planning period
β	Reliability requirement, the probability of net loss should be less than $(1 - \beta)$
p	Failure probability of restoration action at an area
ρ	Correlation coefficient for failure of restoration action between areas
d	Time discounting rate
α	Info-gap robustness parameter, horizon of uncertainty
$\tilde{V}_0(t)$	Best estimate for per unit area conservation value of the development site at time t (per unit area)
$\tilde{V}_i(t)$	Best estimate for per unit area value of compensation area option i at time t
$w_0(t)$	Size of error envelope (weight) of $\tilde{V}_0(t)$
$w_i(t)$	Error weight of $\tilde{V}_i(t)$; with restoration $w_i(t) >> w_0(t)$
$N_{\text{method}}(\alpha, t)$	Number of equal-sized offset areas needed according to an offset calculation using the method indicated by subscript, N_{simple}, N_{IG}, N_{prob}, N_{corr}, and $N_{\text{discounted}}$, for Equations 1, 2, 3, 5, and 7, respectively. This quantity depends on both α and t via Equation 2

restoration land are eventually predicted to hold the same conservation value as the development area.

We extend this solution to consider two sources of uncertainty: (1) that the conservation value achieved at the restoration areas could be less than expected and (2) that the conservation value of the development area could be even better than is thought. In the simplest version, to calculate the robustly fair offset ratio, $N_{\text{IG}}(\alpha, t)$, the info-gap formulation only requires that $\tilde{V}_0(t)$ is replaced by $\tilde{V}_0(t) + \alpha w_0(t)$ and $\tilde{V}_i(t)$ by $\tilde{V}_i(t) - \alpha w_i(t)$ in Equation 1:

$$N_{\text{IG}}(\alpha, t) = \frac{\tilde{V}_0(t) + \alpha w_0(t)}{\tilde{V}_i(t) - \alpha w_i(t)} \tag{2}$$

Here, $w_0(t)$ and $w_i(t)$ are relative error weights for conservation value at the development area and compensation areas at time t in the future. For instance, these envelope functions may derive from statistical modeling and/or expert opinion. Because other experts may have yet other opinions, or differently framed questions may elicit different expert responses, the uncertainty envelopes are multiplied by the unknown horizon of uncertainty, α. In our example $w_0(t)$ and $w_i(t)$ were calculated as the difference between the nominal estimate and the hypothetical error bounds of Figure 1, indicating that at $\alpha = 1$, the uncertainty envelope has expanded to the outer thin lines.

In the next level of sophistication, we allow for the possibility that conservation action in any one land unit could also fail altogether with a probability p. It is then logical to require that the even exchange would be achieved with a given reliability level β, say $\beta = 0.95$. The number of unit areas where conservation action would succeed, N_S, is now distributed binomially as $N_S \sim \text{Bin}(N, p)$. To satisfy the reliability requirement, we need $\text{Prob}[N_S < N_{\text{IG}}(\alpha, t)] < (1 - \beta)$. Denoting by $N_{\text{prob}}(\alpha, t)$, the minimum number of unit areas needed, this number can be determined by finding smallest $N_{\text{prob}}(\alpha, t) > N_{\text{IG}}(\alpha, t)$ for which

$$\sum_{k=0}^{N_{\text{IG}}(\alpha,t)-1} \binom{N_{\text{prob}}(\alpha, t)}{k} (1-p)^{N_{\text{prob}}(\alpha,t)-k} p^k < (1-\beta) \tag{3}$$

Equation 3 assumes statistical independence in success of restoration effort between different sites when calculating $N_{\text{prob}}(\alpha, t)$. The assumption of independence is a strong one, and in general restoration, success between distinct restoration sites would be correlated to some degree (Fig. 3 illustrates effects of correlation). Ovaskainen and Hanski (2003) give a formula for the effective number of independent units, N_{eff}, when there is an uniform level of pairwise correlation, ρ, between N_{corr} sites,

$$N_{\text{eff}} = \frac{N_{\text{corr}}}{1 + \rho(N_{\text{corr}} - 1)} \tag{4}$$

This equation essentially states that if the correlation is ρ, then there can be at most $1/\rho$ independent units irrespective of how many sites there are. Note that Equation 4 ignores higher-order correlations but, even so, it provides useful insight into the influence of correlation on the fair offset ratio.

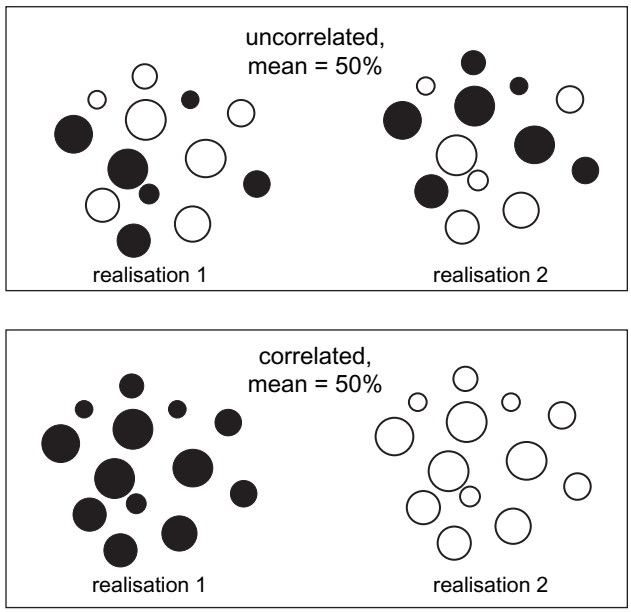

Figure 3. Illustrating effects of correlation. In both the uncorrelated and the correlated cases, the a priori chance of restoration success is 50% per site but the realized patterns are very different. Black and empty circles indicate sites with restoration success and failure, respectively.

Assuming N_{corr} correlated sites, we have only N_{eff} effective independent units, each of average size $S = N_{corr}/N_{eff}$. We then require that unit-size times the minimum number of units that succeed with reliability greater than β must be greater than $N_{IG}(\alpha, t)$. The number of effective units where conservation action would succeed, N_S, is now distributed $N_S \sim \mathrm{Bin}(N_{eff}, p)$. To satisfy the reliability requirement, we need $\mathrm{Prob}[SN_S < N_{IG}(\alpha, t)] < (1 - \beta)$. The minimum number of real units needed for this relation to be true can be determined numerically by finding smallest $N_{corr}(\alpha, t)$, for which

$$\frac{N_{corr}(\alpha, t)}{N_{eff}} N_{min} > N_{IG}(\alpha, t), \tag{5}$$

where N_{eff} comes from Equation 4 and N_{min} is the smallest number of units (out of N_{eff}) that succeed with a probability of at least β. N_{min} can be determined by inspecting the tail of the binomial distribution for the effective number of successful independent units. It is the largest number such that, out of N_{eff} units, at most $N_{min} - 1$ can fail with probability $(1 - \beta)$ or less, which implies that N_{min} or more units will succeed with probability greater than β:

$$\sum_{k=0}^{N_{min}-1} \binom{N_{eff}}{k} (1-p)^{Neff-k} p^k < (1 - \beta). \tag{6}$$

Note that Equation 6 cannot always be satisfied. For example, with $\rho = 0.25$, there can be at most four effective independent units. Then, if the failure probability of a unit is 0.5, a 95% reliability can never be achieved because $0.5^4 = 0.0625 > (1 - 0.95)$ meaning that the chance of all units failing is greater than the 5% allowed.

We add one final component, time discounting, to our analysis. A time-discounted offset ratio can be obtained simply as follows:

$$N_{discounted}(\alpha, t) = \frac{\sum_{t=0}^{t_p} (1 - d)^t N_{method}(\alpha, t)}{\sum_{t=0}^{t_p} (1 - d)^t}, \tag{7}$$

in which d is the time-discounting coefficient and $N_{method}(\alpha, t)$ represents any of the offset ratios from Equations 1, 2, 3, or 5, where the offset calculations have been done at time t using given horizon of uncertainty α. For practical purposes, this means that the offset ratio is weighted most heavily by the early years when the quality of the restoration areas is worst.

Results

We use our simple model to analyze the effects of uncertainty, correlation, and time discounting on the offset ratio. In our example, matching of mean expected utilities gives $N_{simple} = 2$, implying that an exchange could indeed be feasible—that is, by restoring an area twice the size of that lost to development. Figure 4 shows the effects of info-gap uncertainty analysis on the offset ratio (solid line). With $\alpha = 0$, the ratio $N_{IG}(\alpha, t_p) = N_{simple}$, but when α increases, the ratio increases substantially. In the present case, $N_{IG}(1, t_p) = 1.05/0.2 = 5.25$. Hence, accounting for uncertainty in the growth of conservation value makes a large difference to the offset ratio.

Next, we allow for the additional possibility that restoration fails completely in some of the restoration areas, e.g., because the most important focal species fail to migrate/establish there (Suding et al. 2004). We assume that each area has a 0.5 probability of complete failure, $p = 0.5$ in Equations 3 and 6. The number of restoration unit areas needed for replacing the conservation value of the development site with 95% reliability is given by the dashed line in Figure 4. This ratio grows from 1:8 ($\alpha = 0$) to 1:18 ($\alpha = 1$). Allowing uncertainty has thus changed our perception of the number of unit areas needed from 2 to 18. Note that with 18 units, the expected utility is $18 \times 0.5 \times 0.5 = 4.5$, where the halves account for predicted restoration value and the chance of failure. In fact, the expected utility is one quarter of the number of restoration unit areas in all our subsequent analyses.

The solid lines in Figure 5 show the offset ratios we obtain using time discounting (Equation 7; assuming 50% chance of failure per unit area and a 95% reliability requirement). With 1, 3, and 5% time-discounting coefficients, the $\alpha = 1$ offset ratios are now 1:59, 1:82, and 1:95, respectively. Even using no time discounting (0%) but calculating the ratio as an average over the 150-year planning horizon gives a ratio of 1:45 for $\alpha = 1$.

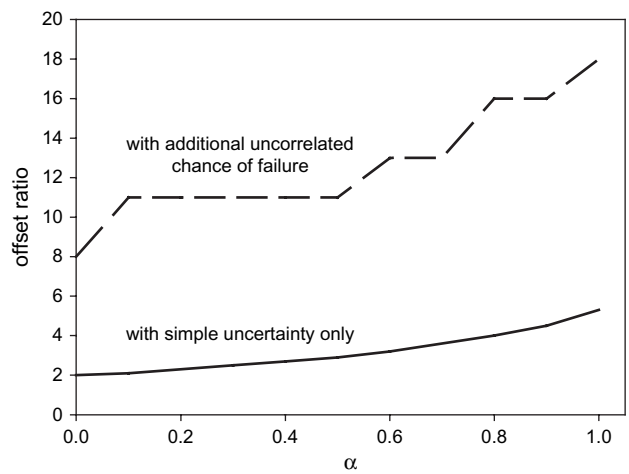

Figure 4. Offset ratio required to get "a fair even exchange" when exchanging one unit area of high conservation value with initially poor-quality restoration compensation areas. The solid line shows the ratio with simple effects of uncertainty ($N_{IG}(\alpha, t)$, with $t = t_p$; Equation 2) and the dashed line shows the respective result, assuming there is an additional uncorrelated per unit area chance of complete failure of restoration activity (N_{prob} assuming $p = 0.5$; Equation 3). (Steps in the dashed line are due to rounding down to integer values when calculating the number of areas needed.)

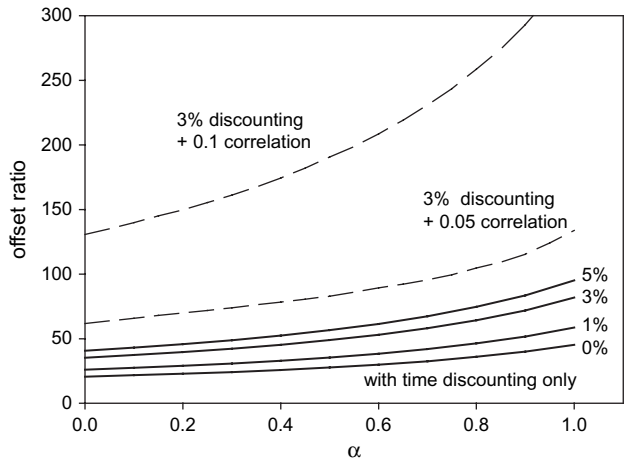

Figure 5. The robustly fair offset ratio when assuming time discounting on top of the uncorrelated chance of failure (solid lines; Equation 7 applied on N_{prob}; cf dashed line in Fig. 2). Offset ratio when adding a further 5 or 10% correlation on top of 3% time discounting (dashed lines; Equation 7 applied on N_{corr}).

We have left for last the hardest factor in our analysis, that is, correlation (dashed lines in Fig. 5). If the restoration success of individual sites is strongly correlated with the restoration success at other sites, then restoration either succeeds in (almost) all sites or fails simultaneously in all sites. Notably, with strong correlation, increasing the number of restoration sites does not notably decrease the probability of complete failure. Figure 5 demonstrates a major influence of correlation on the offset ratio. A small 10% correlation increases the fair offset ratio from approximately 80 to 340 when assuming 3% yearly time discounting.

Discussion

Using various assumptions, our estimate of the fair offset ratio increases quickly from two to hundreds in our simple example. This potentially surprising result is due to the criterion on which we have based our analyses. Instead of using the mean expected value of the restoration areas to determine the offset ratio, we look at the robustness of the proposed exchange in not producing a net loss. These criteria are completely different. The mean expected value criterion is based on the assumption that conservation value of restoration sites grows as expected. However, it is quite possible that although a proposed exchange promises high expected conservation value, it, at the same time, has a high likelihood of (almost) complete failure. This would be the case, e.g., when a large area of similar habitat is restored using a single method, which is not guaranteed to work. In this case, the mean expectation for the conservation value of the restoration areas is high (because the area is large), but the probability of correlated failure across the entire region is large as well (because the effectiveness of the restoration action is not guaranteed). Furthermore, the time evolution of the conservation value of a site is subject to severe info-gap uncertainties.

The influence of time discounting on the offset ratio may be large as well. In fact, if the improvement of conservation value is slow enough, it is questionable whether the habitat should be considered restorable at all (Morris et al. 2006). Still, correlation in restoration success between different areas is the factor that has the greatest influence on the offset ratio in our analysis. Is correlation, of the type we have simulated here, likely to be relevant for real-world planning situations? We believe so. Correlation in restoration success will be increased by (1) uniform habitat quality and environmental conditions across the restoration sites; (2) the same restoration action being applied across all areas; and (3) physical proximity of restoration sites. All these conditions apply commonly in the real world. We would expect an effective absence of correlation only if different restoration actions are applied in different habitat types occurring in different regions. However, if restoration areas are close to each other, some level of correlation is likely to be present. This is because, according to the basic principles of spatial population ecology (Hanski 1998), dispersal and establishment of species into the area will depend on the distance to nearby source areas and on the quality and species composition of these source areas (Donald & Evans 2006). If the restoration sites effectively share the same colonization source areas, then it can be expected that a similar set of species will eventually colonize the restoration areas. Or, if sources are far away, some species of conservation value might fail to reach any of the restoration sites (Bakker et al. 2000). Furthermore, if restoration areas become suitable for the focal species only after a lengthy maturation of vegetation, then it is possible that nearby population sources will disappear before the restoration areas become sufficiently suitable to allow colonization. Correlated failure can of course be avoided by selecting offset areas that already hold reasonable conservation value and therefore require protection rather than restoration.

In summary, when calculating offsets, one should recognize that loss is immediate but gain is uncertain and may not be achieved for a long time into the future. Accounting for uncertainty in offset calculations, and aiming at offsets that robustly avoid net loss, may suggest much higher offset ratios than recommended by matching of mean expected utilities. To obtain a reliably good offset solution, one should employ a bet-hedging strategy, where presently valuable offset areas are preferred, and restoration effort is split among an anticorrelated, or at least uncorrelated, set of sites—that is, where different restoration actions are applied across environmentally different, and spatially dispersed, sites. We emphasize that the offset ratios obtained in our hypothetical example are specific to this example and should not be used as any practical guideline. If compensation areas are of better quality than the development site, then the appropriate offset ratio could even be less than one. The important observation here is the potentially large influence that uncertainty and time discounting could have on fair offset ratios.

The present theoretical analysis is only a first step toward the calculation of robustly fair offset ratios. For example,

we used an aggregate one-dimensional measure of conservation value, whereas in general, one would aim at a satisfactory outcome across a broad range of biodiversity features simultaneously, accounting for complementarity, retention of the features in the landscape, and certainty of species' occurrences in sites. One could require that offsetting is robustly fair for all features simultaneously, which implies potentially large offset ratios and an optimization strategy analogous to target-based reserve selection (Margules & Pressey 2000) accounting for retention (Pressey et al. 2004; Moilanen & Cabeza 2007). An alternative is to require that summed conservation value across features does not decline, allowing a reduction of one feature to be compensated via increased representation for other features, which resembles the additive benefit function approach to reserve selection (Arponen et al. 2005; Moilanen 2007). This approach would allow much flexibility for offsetting, which has potential for both success and misuse.

Also, our analysis does not cover the involved mathematical details of how to handle partial correlation in restoration success between restoration options. We have assumed areas of equal size and cost. Uncertainty could be relevant for many other components of our model, such as the failure probability or correlation, instead of just the development of conservation value at compensation areas. We have also ignored questions of connectivity, spatial population dynamics, and questions of persistence. Performing offset calculations involving such complications will allow for increasingly robust and realistic allocation of habitat restoration effort.

Implications for Practice

- Uncertainty in effectiveness of restoration action should be accounted for when calculating offsets, otherwise a long-term net loss for conservation is likely.
- Time discounting of conservation value, with a rate comparable to the economic return expected from the development site, should be used in offset calculations when conservation value grows slowly in the compensation areas.
- If the same restoration action is applied to a set of environmentally similar sites that are close to each other or effectively combining into one larger compensation area, then success of restoration action is likely to be highly correlated across sites, implying a risk of net loss even if the compensation area is large.
- From an uncertainty–analytic view, the safest offset solution consists of a set of different areas that are treated in variable ways, catering for the needs of partially different groups of species. An informed bet-hedging strategy is less likely to fail a minimal performance requirement (NNL) than a strategy that relies on the success of one particular action at one large compensation area.

Acknowledgments

This study was funded by the Academy of Finland project 1206883 to A.M. and the Finnish Center of Excellence Programme 2006–2011. We thank the University of Melbourne and Australian Centre of Excellence for Risk Analysis for the opportunity to develop this work. P. Vesk and two anonymous reviewers are thanked for constructive comments.

LITERATURE CITED

Arponen, A., R. Heikkinen, C. D. Thomas, and A. Moilanen. 2005. The value of biodiversity in reserve selection: representation, species weighting and benefit functions. Conservation Biology **19:** 2009–2014.

Bakker, J. P., A. P. Grootjans, M. Hermy, and P. Poschlod. 2000. How to define targets for ecological restoration? Applied Vegetation Science **3:**3–6.

Ben-Haim, Y. 2006. Info-gap decision theory: decisions under severe uncertainty. 2nd edition. Academic Press, London, United Kingdom.

Bruggeman, D. J., M. L. Jones, F. Lupi, and K. T. Scribner. 2005. Landscape equivalency analysis: methodology for estimating spatially explicit biodiversity credits. Environmental Management **36:** 518–534.

Carpenter, S. R., W. A. Brock, and D. Ludwig. 2007. Appropriate discounting leads to forward-looking ecosystem management. Ecological Research **22:**10–11.

Cowdy, M. G., and A. F. Carbonell. 1999. Towards consilience between biology and economics: the contribution of Ecological Economics. Ecological Economics **29:**337–348.

Cuperus, R., M. Bakermans, H. A. U. De Haes, and K. J. Canters. 2001. Ecological compensation in Dutch highway planning. Environmental Management **27:**75–89.

Donald, P. F., and A. D. Evans. 2006. Habitat connectivity and matrix restoration: the wider implications of agri-environment schemes. Journal of Applied Ecology **43:**209–218.

Dunford, R. W., T. C. Ginn, and W. H. Desvousges. 2004. The use of habitat equivalency analysis in natural resource damage assessments. Ecological Economics **48:**49–70.

Figge, F., and T. Hahn. 2004. Sustainable value added—measuring corporate contributions to sustainability beyond eco-efficiency. Ecological Economics **48:**173–187.

Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L. Gunderson, and C. S. Holling. 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review of Ecology, Evolution and Systematics **35:**557–81.

Gibbons, P., and D. B. Lindenmayer. 2007. Offsets for land clearing: no net loss or the tail wagging the dog? Ecological Management & Restoration **8:**26–31.

Hanski, I. 1998. Metapopulation dynamics. Nature **396:**41–49.

Harper, D. J., and J. T. Quigley. 2005. No net loss of fish habitat: a review and analysis of habitat compensation in Canada. Environmental Management **36:**343–355.

Hilderbrand, R. H., A. C. Watts, and A. M. Randle. 2005. The myths of restoration ecology. Ecology and Society **10:**19.

Keagy, J. C., S. J. Schreiber, and D. A. Cristol. 2005. Replacing sources with sinks: when do populations go down the drain? Restoration Ecology **13:**529–535.

Margules, C. R., and R. L. Pressey. 2000. Systematic conservation planning. Nature **405:**243–253.

Moilanen, A. 2007. Landscape zonation, benefit functions and target-based planning. Unifying reserve selection strategies. Biological Conservation **134:**571–579.

Moilanen, A., and M. Cabeza. 2007. Accounting for habitat loss rates in sequential reserve selection: simple methods for large problems. Biological Conservation **136:**470–482.

Morris, R. K. A., I. Alonso, R. G. Jefferson, and K. J. Kirby. 2006. The creation of compensatory habitat—can it secure sustainable development? Journal for Nature Conservation **14:**106–116.

National Oceanic and Atmospheric Administration. 2000. Habitat equivalency analysis: an overview. National Oceanic and Atmospheric Administration, Washington, D.C.

Ovaskainen, O., and I. Hanski. 2003. Extinction threshold in metapopulation models. Annales Zoologici Fennici **40:**81–97.

Pressey, R. L., M. E. Watts, and T. W. Barret. 2004. Is maximizing protection the same as minimizing loss? Efficiency and retention as alternative measures of the effectiveness of proposed reserves. Ecology Letters **7:**1035–1046.

Quigley, J. T., and D. J. Harper. 2006*a*. Compliance with Canada's Fisheries Act: a field audit of habitat compensation projects. Environmental Management **37:**336–350.

Quigley, J. T., and D. J. Harper. 2006*b*. Effectiveness of fish habitat compensation in Canada in achieving no net loss. Environmental Management **37:**351–366.

Race, M. S., and M. S. Fonseca. 1996. Fixing compensatory mitigation: what will it take? Ecological Applications **6:**94–101.

Roach, B., and W. W. Wade. 2006. Policy evaluation of natural resource injuries using habitat equivalency analysis. Ecological Economics **58:**421–433.

Sinclair, A. R. E., D. S. Hik, O. J. Schmitz, G. G. E. Scudder, D. H. Turpin, and N. C. Larter. 1995. Biodiversity and the need for habitat renewal. Ecological Applications **5:**579–587.

Suding, K. N., K. L. Gross, and G. R. Houseman. 2004. Alternative states and positive feedbacks in restoration ecology. Trends in Ecology and Evolution **19:**46–53.

ten Kate, K., J. Bishop, and R. Bayon. 2004. Biodiversity offsets: views, experience, and the business case. IUCN, Gland, Switzerland and Cambridge, UK and Insight Investment, London, United Kingdom.

Vesk, P. A., and J. W. Dorrough. 2006. Getting trees on farms the easy way? Lessons from a model of eucalypt regeneration on pastures. Australian Journal of Botany **54:**509–519.

Zedler, J. B. and J. C. Callaway. 1999. Tracking wetland restoration: do mitigation sites follow desired trajectories? Restoration Ecology **7:**69–73.

Environmental Management
DOI 10.1007/s00267-008-9192-5

Biodiversity Offsets: Two New Zealand Case Studies and an Assessment Framework

David A. Norton

Received: 28 February 2008 / Accepted: 22 July 2008
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Abstract Biodiversity offsets are increasingly being used for securing biodiversity conservation outcomes as part of sustainable economic development to compensate for the residual unavoidable impacts of projects. Two recent New Zealand examples of biodiversity offsets are reviewed—while both are positive for biodiversity conservation, the process by which they were developed and approved was based more on the precautionary principal than on any formal framework. Based on this review and the broader offset literature, an environmental framework for developing and approving biodiversity offsets, comprising six principles, is outlined: (1) biodiversity offsets should only be used as part of an hierarchy of actions that first seeks to avoid impacts and then minimizes the impacts that do occur; (2) a guarantee is provided that the offset proposed will occur; (3) biodiversity offsets are inappropriate for certain ecosystem (or habitat) types because of their rarity or the presence of threatened species within them; (4) offsets most often involve the creation of new habitat, but can include protection of existing habitat where there is currently no protection; (5) a clear currency is required that allows transparent quantification of values to be lost and gained in order to ensure ecological equivalency between cleared and offset areas; (6) offsets must take into account both the uncertainty involved in obtaining the desired outcome for the offset area and the time-lag that is involved in reaching that point.

D. A. Norton (✉)
Rural Ecology Research Group, School of Forestry,
University of Canterbury, Private Bag 4800,
Christchurch 8140, New Zealand
e-mail: david.norton@canterbury.ac.nz

Keywords Biodiversity offsets · Environmental compensation · Mitigation · Assessment framework · Resource Management Act · Policy · Restoration

Introduction

Biodiversity offsets are rapidly emerging as an internationally important policy instrument for securing biodiversity conservation outcomes (ten Kate and others 2004). Typically they involve the protection of habitat that either holds existing significant conservation value or where restoration will be undertaken to compensate for the loss of similar values elsewhere. Biodiversity offsets are being used widely by government organizations and the private sector to permit development activities which involve clearance of natural ecosystems and habitats within a framework of no-net-loss or net-gain (ten Kate and others 2004). Although relatively new as a concept, the offset approach has a number of antecedents most notably in North American wetland mitigation projects (Zedler 1996).

Biodiversity offsets have been defined by ten Kate and others (2004) as: "Conservation actions intended to compensate for the residual, unavoidable harm to biodiversity caused by development projects, so as to ensure no net loss of biodiversity."

In North America, biodiversity offsetting is usually referred to as "mitigation." For example, under the no-net-loss policy for wetlands in the United States, unavoidable impacts that damage wetlands (e.g., infilling or draining) must be mitigated by replacement or enhancement elsewhere (Zedler 1996). In Europe, offsetting is more often referred to as compensation, and usually involves habitat creation to offset development impacts (Morris and others 2006).

One of the major criticisms of biodiversity offsets, especially in North America, is that most approved offsets fail to meet their objectives or never actually occur. For example, one study of wetland offsets in Florida found that no mitigation work had even been attempted for 34% of the 63 permits reviewed (Race and Fonseca 1996), while a more recent study of 76 wetland mitigation projects found that 67% failed to create or restore their minimum required area (Matthews and Endress 2008). In Canada, Harper and Quigley (2005) found that offset conditions were not followed in 86% of 124 fish habitat developments.

Notwithstanding these concerns, biodiversity offsetting is now being widely used (ten Kate and others 2004), but the assessment of the ecological costs and benefits of this policy tool have been slower to occur. However, several recent papers (Hilderbrand and others 2005; Harper and Quigley 2005; Morris and others 2006; Gibbons and Lindenmayer 2007; Moilanen and others 2008; Matthews and Endress 2008) provide the basis for the development of a framework for assessing the applicability of biodiversity offsets.

In this article, I initially review two New Zealand development proposals where offsets have been proposed and accepted by the New Zealand environmental planning process, and then outline an environmental framework within which to consider the use of biodiversity offsets. Given that biodiversity offsets sit at the nexus between environmental science and policy, this framework will assist both those developing offset proposals, and the regulatory authorities consenting such proposals, to ensure that offsets do meet the no-net-loss of biodiversity definition (ten Kate and others 2004).

New Zealand Examples of Biodiversity Offsets

In New Zealand, the management of natural resources, including the clearance of indigenous vegetation, is governed by objectives, policies, and methods, including rules that are developed by local authorities (city/district and regional councils) and outlined in city/district and regional plans. These rules set the bounds for a wide range of different land and water uses and activities and are developed within the context of the New Zealand Resource Management Act 1991 (RMA; Memon and Gleeson 1995). The purpose of the RMA is to ensure the sustainable management of natural and physical resources (Section 5[1]), where sustainable management is defined as (Section 5[2]):

> "managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety while:
>
> (a) Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and
> (b) Safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and
> (c) Avoiding, remedying, or mitigating any adverse effects of activities on the environment."

Anyone who wishes to undertake activities that are not permitted in relevant city/district or regional plans must apply for resource consent(s) for the activity. These applications are considered by the relevant council in terms of both the provisions of their plan and the RMA itself. The decisions reached from these deliberations can then be appealed to the Environment Court which then re-hears the whole case before reaching a decision. Expert witnesses play a key role in placing technical and scientific material before the consent hearing or Court. While Environment Court decisions can be appealed to higher courts, such appeals are only on points of law and are uncommon. It is the Environment Court that clarifies the intent of the RMA and thus sets the case law which guides consideration of other applications. Where development results in what are considered as "more than minor" effects on the environment, then the applicant needs to show how they will "avoid, remedy or mitigate" effects.

The application of biodiversity offsets in New Zealand is relatively new (Borrie and others 2004; Christensen 2007). The idea of biodiversity offsets, usually called environmental compensation, has been considered in several recent decisions of the New Zealand Environment Court. In the Court's decision on the J F Investments Limited case (C48/2006) the Court defined environmental compensation as: "Any action (work, services or restrictive covenants) to avoid, remedy or mitigate adverse effects of activities on a relevant area, landscape or environment as compensation for the unavoided and unmitigated adverse effects of the activity for which consent is being sought."

The following examples illustrate the way in which the biodiversity offset concept has been applied in New Zealand and are typical of recent development projects that have included offset or compensation proposals.

Kate Valley Landfill

Kate Valley is located in coastal hill country in New Zealand's eastern South Island (Motunau Ecological District, 43° 06′ S, 172° 51′ E, 0-346 m a.s.l.; Norton 2005). The underlying geology comprises Tertiary seabed strata dominated by fine-grained compacted sedimentary deposits including limestone and mudstone. Annual rainfall is 921 mm but with considerable variation within and between years. The area typically experiences warm dry summers

Table 1 Kate Valley vegetation types at the time the biodiversity offset proposal was developed (Norton 2005)

Vegetation type	% land area
Exotic pasture	60
Kunzea ericoides shrubland and low forest	15
Indigenous shrubland	10
Exotic shrubland	7
Exotic conifer plantations	3
Wetland	4
Old growth *Nothofagus solandri* forest	1

and cool wet winters. Snow is rare, although frost can occur in winter, especially in valley bottoms away from the coast. The property has had a mixed farming history, but because of erosion and weed problems has been typically farmed as an extensive sheep and cattle property.

Pasture is the dominant vegetation type (Table 1). While some very small (<1 ha) remnants of old growth indigenous forest remain, the predominant indigenous vegetation is seral *Kunzea ericoides* (kanuka) shrubland and low forest with varying mixtures of other regenerating indigenous tree species, and mixed indigenous shrubland, although this accounts for 25% of the land area. All forest and shrubland areas have been strongly modified by domestic stock and are typically devoid of regeneration except in inaccessible sites.

After a long period of investigation, Transwaste Canterbury Ltd. (TCL) identified Kate Valley as the preferred site for a new regional landfill and applied in 2002 to Hurunui District Council for resource consent. TCL is a 50/50 public/private joint venture between local government and two waste management companies The consent was granted in 2003 subject to a number of conditions, some of which TCL felt were too restrictive while parties in opposition to the landfill felt that consent should have been declined in its entirety. One matter that was the subject of debate was a condition of the consent that required a <1 ha remnant of *Nothofagus solandri* (black beech) forest (referred to as 'Remnant A') be retained. TCL wished to see this removed to enable the landfill to be of a viable size while opposing parties wanted it to stay. TCL and three opposing parties filed appeals to the Environment Court which heard the case in September–November 2003. As part of their appeal TCL revisited a number of elements of the project including the environmental compensation (biodiversity offset) being offered and put a new and substantially bigger offset package before the Court. The Court accepted the biodiversity offset proposed and granted consent for the revised proposal including allowing removal of "Remnant A." (Environment Court decision C29/2004, 22 March 2004).

The biodiversity offset proposal accepted by the Court involved the long-term protection, restoration, and management of a 410 ha "Conservation Management Area" adjacent to the Kate Valley landfill (now known as Tiromoana Bush; www.tiromoanabush.co.nz). The Court further specified that the consent holder (TCL) must at its own cost undertake a number of actions including:

- Register a covenant against the title which provides legal protection in perpetuity of Tiromoana Bush prior to the acceptance of first waste.
- Permanently fence Tiromoana Bush and remove all domestic grazing animals within two years of the issuing of the consent and prior to the acceptance of first waste.
- Within two years of the issuing of the consent, and prior to the acceptance of first waste, commission and submit a detailed restoration plan for Tiromoana Bush.
- Commence and continue implementation of the Restoration Plan in accordance with the priorities and timeframes outlined in the Restoration Plan including:
    - producing an annual report on progress on the Restoration Plan.
    - sourcing all plant species used for planting either from Tiromoana Bush itself or from the southern part of the Motunau Ecological District.
    - initiating and continuing animal and plant pest control programmes within Tiromoana Bush during the operating life of the landfill.
    - carrying out propagation and transplanting of *Nothofagus solandri* seedlings from Remnant A into Tiromoana Bush.
    - providing controlled public access for recreational, educational and scientific use to Tiromoana Bush by a walking track.
- The costs of the obligations arising under this condition are to be funded directly by TCL, with such funding being independent of and not reliant upon cashflow from the landfill.

The Tiromoana Bush Restoration Management Plan (Norton 2005) identified three components to the restoration work; natural regeneration of the remnant indigenous forest areas as a result of removal of domestic grazing animals, natural regeneration in pasture areas as a result of removal of domestic grazing animals, and establishment of restoration plantings to enhance connectivity between remnant patches and to reintroduce key plant species for indigenous fauna.

Waikatea Station Farm Development

Waikatea Station (3570 ha) is typical of sheep and cattle farms that occur through the hill country of New Zealand's eastern North Island (Tiniroto Ecological District, 38° 46′

Table 2 Waikatea Station vegetation types at the time the biodiversity offset proposal was developed (Norton 2007)

Vegetation type	% land area
Exotic pasture	57
Kunzea ericoides shrubland and low forest	23
Poor quality exotic pasture	14
Regenerating Podocarpaceae forest	4
Old growth Podocarpaceae forest	1
Indigenous shrubland	1

S, 177° 29′ E, 80-537 m a.s.l.; Norton 2007). The underlying geology comprises young sedimentary rocks mainly of late Tertiary age, especially sandstone, siltstone, and mudstone. The topography is generally steep, with sharp hill crests separated by incised river systems. Waikatea Station is estimated to receive an annual average rainfall of 1400–1600 mm, with most rain falling in winter, while summers can be dry, although drought is usually not a problem. From a farming perspective, Waikatea Station is considered a well balanced property. In 2004, the property wintered 19,000 stock units (43% sheep and 57% cattle).

The most widespread vegetation type on Waikatea Station is pasture (Table 2), dominated by exotic grass and herb species (Norton 2007). However, 29% of the property supports indigenous forest and shrubland (mainly dominated by *Kunzea ericoides*) much of it of recent origin having established on areas that were previously under pasture. Indigenous forest and shrubland is heavily undergrazed by farmed cattle and sheep, and feral goats. The dominant understorey plants are species of low palatability, while palatable understorey species, including seedlings and saplings of most of the canopy dominants, are rare or absent. Undergrazing is used as part of farm management, especially during winter when feed is in short supply. Under this regime, forest regeneration is unlikely and canopy collapse is possible once the current seral canopy *Kunzea ericoides* start to senesce.

In November 2004 the Bayly Trust, who own Waikatea Station, applied to Wairoa District Council for resource consent to clear 536 ha of *Kunzea ericoides* shrubland and low forest for pasture reestablishment, while protecting a further 674 ha of forest remnants and riparian zones. Following the resource consent hearing at which the Department of Conservation (DOC, a central government agency which manages public conservation land and advocates for preservation on private land) opposed the application, the Council granted consent in March 2006 which, subject to conditions, authorized the clearance of 356 ha of *Kunzea ericoides*. DOC then appealed this decision to the Environment Court which heard the case in July/August 2007. A revised proposal involving the clearance of 354 ha of *Kunzea ericoides* shrubland and low forest for pasture development, and protection through covenanting and fencing of a further 799 ha of forest and shrubland as a biodiversity offset was put to the Environment Court at this hearing. Although DOC expert witnesses at the hearing claimed that the project, including the offset proposal, would result in a net loss of biodiversity on the property, the Court accepted expert evidence that there would in fact be a net-gain in biodiversity because of the removal of grazing animals from the 799 ha to be protected and granted consent for the revised proposal (Environment Court decision W081/2007, 19 September 2007).

The biodiversity offset proposal accepted by the Court involved:

- Permanent protection of 799 ha of indigenous forest and shrubland, together with some areas of pasture (primarily riparian areas), through a QEII National Trust Open Space Covenant (www.openspace.org.nz) on the property title.
- Removal of domestic grazing pressure from all protected areas through the establishment of new fencing and the repair of existing fencing, and then the removal of all domestic grazing animals.
- Active control of feral grazing and browsing animals especially goats and brushtail possums.
- Monitoring of biodiversity values.
- Natural regeneration of pasture areas included within the covenanted and fenced area once they have been retired from grazing.

The areas selected for protection and fencing were chosen to be (Norton 2007):

- Inclusive of all remaining areas of remnant old growth forest.
- Fully representative of the range of environments that occur on Waikatea Station (especially with respect to altitude, aspect and landform).
- Large enough to be well buffered and have good resilience (the ability to recover from natural disturbances).
- Provide connectivity between protected areas, and with other areas of indigenous forest outside the property, both for aquatic and terrestrial biota.
- Provide habitat for nationally uncommon species, especially fauna.

Framework for Assessing Biodiversity Offsets

While substantial biodiversity offsets were approved as part of the regulatory process in the case studies, the manner in which they were developed was based more

around the precautionary principal than from the application of a formal assessment framework. Given the increasing uptake of biodiversity offsets internationally (ten Kate and others 2004) it is important that the merits of individual proposals are rigorously assessed against an appropriate framework. The recent literature on biodiversity offsets provides the basis for such a framework. Based on both the case studies and this literature, a preliminary framework of key environmental principles, which should be considered in developing and evaluating biodiversity offsets, is now proposed.

The six principles fall into two groups; the first two are primary socio-economic principles, in that they are concerned with the process by which offsets are considered and implemented while the remaining four are primarily ecological, as they are concerned with the selection and quantification of offsets. Notwithstanding this distinction, all six principals are relevant for both the design of offsets (a largely ecological process) and their approval and implementation within regulatory frameworks (a regulatory/policy process).

Principle One

Biodiversity offsets should only be used as part of an hierarchy of actions in which a development project must first seek to avoid impacts and then minimize the impacts that do occur (ten Kate and others 2004; Moilanen and others 2008). Offsets are an activity that compensates for the residual, unavoidable impacts (harm) after avoiding and minimizing as much as possible.

The use of such an hierarchical approach explicitly places biodiversity offsets within a broader context of responsible development. A development project must first seek to avoid any adverse impacts, or when these are unavoidable, it should seek to minimize such impacts. Only when these steps have been addressed and there is still residual impact (e.g., through vegetation clearance), can offsets be considered as a compensation mechanism. Biodiversity offsets should not be used to justify adverse impacts; rather they are the final step in a process that focuses first on avoidance and minimization. However, the way in which such an hierarchy is used will necessarily reflect the local policy/regulatory situation and there may be cases where a favorable offset might be accepted where the "avoid" option is less attractive on social or economic grounds.

In the Kate Valley case, a rigorous process was undertaken to identify the best site for the regional landfill that had to meet geotechnical, logistical, and environmental concerns (including avoiding damaging or destroying significant indigenous habitat). While no single site could totally avoid all impacts, the Kate Valley site was considered the best. The Waikatea situation was more complex as the land owner was restricted to the one location and wished to increase the area of pasture. This meant that "avoidance" was not possible in terms of clearance of indigenous vegetation. However, the direct impacts of clearance were minimized by ensuring that the areas that were not to be cleared (the offset) would offer the best outcome for the sustainable conservation of indigenous biodiversity on the property.

Principle Two

Some form of guarantee must be provided that the offset proposed will occur (Race and Fonseca 1996; Harper and Quigley 2005; Gibbons and Lindenmayer 2007; Matthews and Endress 2008).

One of the major criticisms of offsets, especially in North America, is that most approved offsets fail to meet their objectives or never actually occur (e.g., Race and Fonseca 1996; Matthews and Endress 2008; Harper and Quigley 2005). In approving biodiversity offsets as part of economic development projects, consenting authorities must ensure that adequate systems are put in place to ensure that compliance does occur. Furthermore these systems must be robust enough to take into account the time-lags that are likely to occur in achieving a desired offset outcome (see principle six).

In New Zealand, the Environment Court will usually include specific conditions relating to biodiversity offsets that must be met prior to a development project commencing and, in some cases, to enable its continuation. In both the Kate Valley and Waikatea Station cases this included requirements for covenanting, cessation of grazing and management plan development (Kate Valley only) prior to commencement of development work. However, the biggest weakness in ensuring that offset conditions are enforced is a lack of relevant expertise within consenting authorities to monitor offset projects. While a guarantee is important from the developer, there also needs to be the ability to enforce the offset requirements to ensure that the proposed outcomes are actually realized.

Principle Three

Biodiversity offsets are inappropriate for certain ecosystem (or habitat) types because their rarity or the presence of particular species within them makes the clearance of these ecosystems inappropriate under any circumstances (Gibbons and Lindenmayer 2007).

Notwithstanding the hierarchy in principle one, it seems clear that there are some ecosystems or habitat types for which offsets are never going to be possible. These may be ecosystems that have already been diminished to such an

extent that any further loss is unacceptable, or habitats of species whose loss would most likely lead to the extinction of the species as well. In the United States, the Endangered Species Act 1973 imposes specific requirements on developers to avoid impacting on listed species (Stokstad 2005). There may also be situations where the impact of a development will have adverse off-site effects, for example, through alteration of ecological processes (e.g., hydrological regimes) which results in further habitat loss and/or species extinction at other sites. Specific thresholds to trigger this principle will vary depending on the local situation but may include the presence of species listed as nationally threatened or of habitats that have less than a particular percentage of their total area remaining (e.g., <10%).

In New Zealand, published lists of threatened species and habitats (de Lange and others 2004; Walker and others 2005) provide a framework for the Environment Court to consider if clearance is permissible, but there is no statutory basis for restricting development as is the case with the Endangered Species Act. In both the Kate Valley and Waikatea cases, the Environment Court determined, based on detailed ecological evidence, that while indigenous biodiversity would be lost, it was not of such value that clearance was inappropriate. In the Kate Valley case, the Court determined that the remnant old growth forest was not significant, while in the Waikatea case, the Court concluded that while the indigenous vegetation proposed for clearance was significant, the effects of the proposed clearance were not sufficient to justify refusal of the application given the nature of the offset proposed.

Principle Four

Biodiversity offsets can involve protection of existing habitat but most often involve the creation of new habitat, especially when existing habitat already enjoys a degree of protection (Gibbons and Lindenmayer 2007).

While a biodiversity offset might involve the protection of an area of intact indigenous vegetation, offsetting normally involves the restoration and protection of new areas/habitats. In North America, wetland mitigation has focused primarily on creating new wetlands to offset impacts on existing wetlands (Zedler 1996; Race and Fonseca 1996; Matthews and Endress 2008), and this is also the case in the United Kingdom (Morris and others 2006). While it might be possible to include the protection of an existing area of indigenous habitat from clearance, the concept of "duty of care" (Gibbons and Lindenmayer 2007) means that this approach may still result in a net-loss of habitat if there are already mechanisms in place to limit the loss of the offset area (e.g., through local or regional plans). However, the use of existing indigenous habitat for offsets might be appropriate where "protection" results in a significant improvement in "condition" over what is the current or likely future condition.

In both the Kate Valley and Waikatea cases the biodiversity offset involved both the protection of existing habitat and the creation of new habitat, although the relative importance of these differed. At Kate Valley, the 410 ha Tiromoana Bush restoration area is a mixture of pasture (57 %), and indigenous shrubland and low forest (43 %). In contrast at Waikatea Station, the 799 ha offset area is predominantly indigenous shrubland and forest (79 %), with a much smaller area of pasture (21 %). However, in both cases, the "health" of the existing habitat is severely degraded because of the pervasive impacts of domestic and feral grazing and browsing mammals, a major problem in many New Zealand forests (Wardle and others 2001; Coomes and others 2003; Smale and others 2008), and it is likely that these animals will continue to suppress any palatable plant species, including forest canopy regeneration, resulting in nonreversible forest degradation. Thus the offset proposal will result in a significant improvement in the condition of the existing habitat because of the exclusion and control of invasive mammals.

Principle Five

A clear currency is required that allows transparent quantification of values to be lost and values to be gained in order to ensure ecological equivalency between cleared and offset areas (Salzman and Ruhl 2000; McCarthy and others 2004; ten Kate and others 2004; Morris and others 2006; Gibbons and Lindenmayer 2007; Moilanen and others 2008).

Any biodiversity offset proposal must be founded on very good knowledge of the biodiversity values of both the site that is to be impacted and the offset site, including composition, structure and pattern, function, and dynamics and resilience of the system (Hobbs and Norton 1996). The development of a clear currency to quantify the values at different sites being considered as part of biodiversity offsets is essential to ensure that clearance of high quality habitat or a rare ecosystem is not offset using an area of low quality habitat or common ecosystem and thus that biodiversity offsets have credibility.

A range of approaches to optimising conservation outcomes at the landscape scale have been proposed (Pressy and others 2007; Wilson and others 2007; Kremen and others 2008) and provide the opportunity to ensure that the location of offset sites are optimized to ensure that there is no-net-loss or even a net-gain in biodiversity. However, to utilize these tools as part of offset development, good quantitative knowledge of the biodiversity values present

both within the target sites and at other sites within the broader landscape is required.

A clear currency is also essential if there is to be any objective determination of appropriate offset ratios (Gibbons and Lindenmayer 2007). While a number of metrics have been proposed (e.g., Parkes and others 2003; McCarthy and others 2004; Bruggeman and others 2006), the size of offsets has usually been based on subjective judgments (Morris and others 2006). The development of appropriate ratios for compensation may be important if there is to be a fair exchange of areas, but any such assessment must take into account the uncertainties discussed below (Moilanen and others 2008).

In both the Kate Valley and Waikatea Station cases, the offset areas are located adjacent to the clearance areas and involved the same ecosystem types. Detailed ecological information (species lists, community comparisons, quantification of historical ecosystem change, and regional analyses of habitat types) was presented to the Environment Court which enabled the Court to reach conclusions on the relative merit of the biodiversity offset proposed, although no formal offset ratio was proposed or optimization approach used in determining the outcome.

Principle Six

Determination of what is an appropriate offset must take into account both the uncertainty involved in obtaining the desired outcome for the offset area and the time-lag that is often involved in reaching this point (Zedler 1996; Hilderbrand and others 2005; Morris and others 2006; Moilanen and others 2008).

Uncertainty relates primarily to the inability of ecologists to accurately predict what a system will be like at some point in the future as a result of management actions implemented as part of the offset (e.g., restoration). Uncertainty is particularly high where offsets involve restoration of significantly modified sites (e.g., abandoned farmland) or where there are strong abiotic drivers of ecosystem processes that need to be reversed (e.g., disturbance regimes or hydrological factors) and there is no guarantee that the desired outcome will be achieved (Hilderbrand and others 2005). Uncertainty will be less where the offset involves, for example, the removal of a degraded influence, such as an herbivore or predator, in an otherwise intact ecosystem. However, uncertainty is exacerbated by the extinction debt associated with past and current habitat loss (Tilman and others 1994; Schrott and others 2005) which makes it difficult to predict future condition in highly fragmented landscapes irrespective of the development and associated offset proposal.

Offsets also need to allow for the delayed time that is involved in achieving the desired biodiversity outcome, especially when the economic development will be yielding economic benefits in a much shorter time frame than the ecological changes will be occurring over. Uncertainty and time-lags also present challenges for consenting authorities who need to factor these into the conditions that are imposed as part of a development consent—for example, the time period over which a bond might need to be held or the procedures that are established to monitor compliance.

One way to overcome uncertainty is through the use of biodiversity banks. These involve a third party owning an area that has been restored, established, enhanced, or (in certain circumstances) preserved for the purpose of trading with a developer who requires an offset as part of a development project. Wetland mitigation banks have been used extensively in the United States (Weems and Canter 1995) and enable a developer to purchase an offset prior to undertaking their development work, thus reducing some of the uncertainties associated with establishing a new offset. Bonnie (1999) suggests a similar approach for offsetting unavoidable adverse impacts on endangered species habitat, while habitat banks fulfill a similar function in Europe (Morris and others 2006).

In the Kate Valley and Waikatea Stations cases, two main areas of uncertainty were identified; (1) that the remnant indigenous forests will regenerate once the degrading influences had been removed, and (2) that natural regeneration and/or restoration plantings will be successful in re-establishing self-sustaining indigenous forest ecosystems in pasture areas. Both of these were addressed during the Environment Court process with ecological evidence presented to show that both were unlikely to be a major issue based on previous New Zealand research (Reay and Norton 1999; Dodd and Power 2007). The Court took this evidence into account in reaching its decision on the appropriate offset.

Conclusions

The environmental framework presented here provides a basis for assessing the potential usefulness of biodiversity offsets as a policy instrument in sustainable development and should assist both those developing offset proposals and consenting authorities evaluating such proposals. While there are instances where biodiversity offsets are going to be totally inappropriate (Gibbons and Lindenmayer 2007), offsets are likely to be increasingly used as people strive to meet environmental and social, as well as economic, standards in project development. The six principles outlined here provide a framework for both developing and assessing future biodiversity offset proposals, although they do not provide guidance on

determining specific offset ratios (Moilanen and others 2008).

While it is possible to undertake detailed assessment of the values present at both the impact and offset site, the lack of any guarantee that an offset proposed will be realized is a significant problem with biodiversity offsets worldwide (Race and Fonseca 1996; Harper and Quigley 2005; Gibbons and Lindenmayer 2007; Matthews and Endress 2008). It is essential that when a condition requiring biodiversity offsetting is included when permitting a project development, that consenting or decision-making authorities should also ensure that the biodiversity offsetting work is substantially implemented prior to that development work commencing. In the Kate Valley case, this was done with a requirement for the completion of certain activities prior to any refuse being taken to the landfill. Ensuring that such enforceability is built into offset proposals is likely to be the biggest challenge for the future application of biodiversity offsets and it is beholden on the developer as well as regulatory authorities to ensure that workable methods for doing this are put in place. However, to be enforceable, consenting authorities need to have the relevant expertise to monitor offset projects.

The determination of appropriate offset ratios is likely to become an increasingly important part of biodiversity offsetting. However, the use of such ratios needs to be balanced by the need to ensure that solutions are appropriate to the local (country or region) situation, both in terms of biodiversity and social context. A degree of flexibility, but based on the precautionary principle, operating within a sound environmental framework (as outlined here) is likely to result in better biodiversity outcomes than adherence to a rigid offset ratio that might not be appropriate in every situation. However, it is likely that because of the uncertainties in future outcomes (e.g., Zedler 1996; Hilderbrand and others 2005; Morris and others 2006; Gibbons and Lindenmayer 2007) high offset ratios may be required in many instances to guarantee a robust fair exchange (Moilanen and others 2008).

Acknowledgments Many thanks to Hamish Cochrane for assistance with GIS analyses, Atte Moilanen and Judith Roper-Lindsay for constructive comments on drafts of this article, and to three referees for their comments which helped shape the final form of this article.

References

Bonnie R (1999) Endangered species mitigation banking: promoting recovery through habitat conservation planning under the Endangered Species Act. The Science of the Total Environment 240:11–19

Borrie N, Memon A, Skelton P (2004) An international perspective on environmental compensation: lessons for New Zealand's resource management regime. Research Monograph, Environment, Society and Design Division. Lincoln University, Canterbury, New Zealand

Bruggeman DJ, Jones ML, Lupi F, Scribner KT (2006) Landscape equivalency analysis: methodology for estimating spatially explicit biodiversity credits. Environmental Management 36:518–534

Christensen M (2007) Biodiversity offsets—an overview of selected recent development: New Zealand—where to from here? Unpublished report, Anderson Lloyd Lawyers, Christchurch, New Zealand

Coomes DA, Allen RB, Forsyth DM, Lee WG (2003) Factors preventing the recovery of New Zealand forests following control of invasive deer. Conservation Biology 17:450–459

de Lange PJ, Norton DA, Heenan PB, Courtney SP, Molloy BPJ, Ogle CC, Rance BD, Johnson PN, Hitchmough R (2004) Threatened and uncommon plants of New Zealand. New Zealand Journal of Botany 42:45–76

Dodd MB, Power IL (2007) Recovery of tawa-dominated forest fragments in the Rotorua Basin, New Zealand, after cessation of livestock grazing. Ecological Management and Restoration 8:208–217

Gibbons P, Lindenmayer DB (2007) Offsets for land clearing: no net loss or the tail wagging the dog? Ecological Management and Restoration 8:26–31

Harper DJ, Quigley JT (2005) No net loss of fish habitat: a review and analysis of habitat compensation in Canada. Environmental Management 36:343–355

Hilderbrand RH, Watts AC, Randle AM (2005) The myths of restoration ecology. Ecology and Society 10(1):19. http://www.ecologyandsociety.org/vol10/iss1/art19/

Hobbs RJ, Norton DA (1996) Towards a conceptual framework for restoration ecology. Restoration Ecology 4:93–110

Kremen C, Cameron A, Moilanen A, Phillips S, Thomas CD, Beentje H, Dransfeld J, Fisher BL, Glaw F, Good T, Harper G, Hijmans RJ, Lees DC, Louis E Jr, Nussbaum RA, Raxworthy C, Razafimpahanana A, Schatz G, Vences M, Vieites DR, Wright PC, Zjhra ML (2008) Aligning conservation priorities across taxa in Madagascar, a biodiversity hotspot, with high-resolution planning tools. Science 320:222–226

Matthews JW, Endress AG (2008) Performance criteria, compliance success, and vegetation development in compensatory mitigation wetlands. Environmental Management 41:130–141

McCarthy MA, Parris KM, van der Ree R, McDonnell MJ, Burgman MA, Williams NSG, McLean N, Harper MJ, Meyer R, Hahs A, Coates T (2004) The habitat hectares approach to vegetation assessment: an evaluation and suggestions for improvement. Ecological Management and Restoration 5:24–27

Memon PA, Gleeson BJ (1995) Towards a new planning paradigm? Reflections on New Zealand's Resource Management Act. Environment and Planning B Planning and Design 22:109–124

Moilanen A, van Teeffelen AJA, Ben-Haim Y, Ferrier S (2008) How much compensation is enough? A framework for incorporating uncertainty and time discounting when calculating offset ratios for impacted habitat. Restoration Ecology 16:in press

Morris RKA, Alonso I, Jefferson RG, Kirby KJ (2006) The creation of compensatory habitat–can it secure sustainable development? Journal of Nature Conservation 14:106–116

Norton DA (2005) Tiromoana Bush restoration project management plan. Transwaste Canterbury Ltd., Christchurch, New Zealand. [available at URL http://www.tiromoanabush.co.nz]

Norton DA (2007) Using biodiversity offsets to obtain "win-win' outcomes for biodiversity conservation and economic production. New Zealand Journal of Forestry 52(3):36–40

Parkes D, Newell G, Cheal D (2003) Assessing the quality of native vegetation: the 'habitat hectares' approach. Ecological Management and Restoration 4:S29–S38

Pressey RL, Cabeza M, Watts ME, Cowling RM, Wilson KA (2007) Conservation planning in a changing world. TREE 22:583–592

Race MS, Fonseca MS (1996) Fixing compensatory mitigation: what will it take? Ecological Applications 6:94–101

Reay SD, Norton DA (1999) Assessing the success of restoration plantings in a temperate New Zealand forest. Restoration Ecology 7:298–308

Salzman J, Ruhl JB (2000) Currencies and the commodification of environmental law. Stanford Law Review 53:607–694

Schrott GR, With KA, King AW (2005) On the importance of landscape history for assessing extinction risk. Ecological Applications 15:493–506

Smale MC, Dodd MB, Burns BR, Power IL (2008) Long-term impacts of grazing on indigenous forest remnants on North Island hill country, New Zealand. New Zealand Journal of Ecology 32:57–66

Stokstad E (2005) What's wrong with the Endangered Species Act? Science 309:2150–2152

ten Kate K, Bishop J, Bayon R (2004) Biodiversity offsets: views, experience and the business case. IUCN, Gland, Switzerland and Insight Investment, London, UK

Tilman D, May RM, Lehman CL, Nowak MA (1994) Habitat destruction and the extinction debt. Nature 371:65–75

Walker S, Price R, Rutledge D (2005) New Zealand's remaining indigenous cover: recent changes and biodiversity protection needs. Landcare Research Contract Report: LC0405/038 prepared for the Department of Conservation. http://www.landcareresearch.co.nz/services/informatics/lenz/downloads/New%20Zealand_indigenous_cover.pdf

Wardle DA, Barker GM, Yeates GW, Bonner KI, Ghani A (2001) Introduced browsing mammals in New Zealand natural forests: aboveground and belowground consequences. Ecological Monographs 71:587–614

Weems WA, Canter LW (1995) Planning and operational guidelines for mitigation banking for wetland impacts. Environmental Impact Assessment Review 15:197–218

Wilson KA, Underwood EC, Morrison SA, Klausmeyer K, Murdoch W, Reyers B, Wardell-Johnson G, Marquet PA, Rundel PW, McBride MF, Pressey RL, Bode M, Hoekstra JM, Andelman S, Looker M, Carlo Rondinini C, Kareiva P, Shaw MR, Possingham HP (2007) Conserving biodiversity efficiently: what to do, where, and when. PLoS Biology 5:1850–1861

Zedler JB (1996) Ecological issues in wetland mitigation: an introduction to the forum. Ecological Applications 6:33–37

RANGE-WIDE MONITORING OF THE MOJAVE POPULATION OF THE DESERT TORTOISE:

2007 ANNUAL REPORT

PREPARED BY LINDA ALLISON
DESERT TORTOISE MONITORING COORDINATOR
U.S. FISH AND WILDLIFE SERVICE

OCTOBER 2009

Recommended Citation: U.S. Fish and Wildlife Service. 2009. Range-wide Monitoring of the Mojave Population of the Desert Tortoise: 2007 Annual Report. Report by the Desert Tortoise Recovery Office, U.S. Fish and Wildlife Service, Reno, Nevada.

TABLE OF CONTENTS

Executive Summary 5
Introduction 9
Methods 10
Study areas and transect locations 10
Modification of previous procedures 10
Field observer training 13
Proportion of tortoises detected at varying distances from the transect centerline 15
Tortoise encounter rate and development of detection functions 15
Proportion of tortoises that are available for detection by line distance sampling, G_0 16
Modification of previous procedures 16
Proportion of available tortoises detected on the transect centerline, *g(0)* 18
Estimates of tortoise density 19
Modification of previous procedures 21
Debriefing to describe strengths and weaknesses of project preparation and execution .. 21
Results 21
Field observer training 21
Proportion of tortoises detected at varying distances from the transect centerline 23
Transect completion 27
Tortoise encounter rates and detection functions 33
Proportion of tortoises that are available for detection by line distance sampling, G_0 34
Proportion of available tortoises detected on the transect centerline, *g(0)* 35
Estimates of tortoise density 37
Debriefing to identify strengths and weaknesses in preparation for future years 39
Discussion 44
Sampling representatively in all monitoring strata 44
Estimation and use of G_0 to adjust density calculations 45
Improving ability to detect trends in desert tortoise abundance 46
Impact of developing regional G_0 estimates 46
Consequences of insufficient transects 47
Reporting density estimates at other relevant spatial scales 48
Literature Cited 48
Appendix A. Guidelines for Non-Standard Transects 50
Appendix B: Estimating G_0 and its associated variance 53
Appendix C: Updates to Tables 7 and 8 of the 2001-2005 Summary Report (USFWS 2006) 61
Appendix D: Original and Recalculated Recovery Unit Density Estimates, 2001 to 2005 73

LIST OF TABLES

Table 1. Scenarios explored in Anderson and Burnham (1996) and associated power for a one-tailed test. 12
Table 2. Training schedule for 2007 14
Table 3. Diagnostics for individual teams after training 23
Table 4. Proportion of tortoise models detected within 1-, 2-, or 5-m of the transect center line. 24
Table 5. Proportion of tortoise models that were detected by the leader (single-observer) or leader-follower team (dual-observer) following training, 2004-2007. 26
Table 6. Number and type of transects in each stratum. 32
Table 7. Availability of tortoises (G_0) during the period in 2007 when transects were walked in each group of neighboring strata 35
Table 8. Recovery unit and stratum-level encounters and densities in 2007 for tortoises with MCL ≥ 180mm 38
Table 9. Estimated density of desert tortoises in monitored areas of each recovery unit in the Mojave Desert in 2007. 39
Table 10. Training modules to have objectives, standards, and metrics developed for 2008 41
Table 11. Planned and actual timelines for desert tortoise monitoring in 2007 and planned completion dates for the 2008 field season. 43
Table 12. Comparison of estimated G_0 and percent CV(G_0) at telemetry sites monitored in 2005 and 2007. 47
Table 13. Abbreviations for transect strata and telemetry sites. 62
Table 14. 2001 estimates of encounter rates, proportion of tortoises that were visible, and detection rates. 63
Table 15. 2001 density estimates for monitoring strata and recovery units 64
Table 16. 2002 estimates of encounter rates, proportion of tortoises that were visible, and detection rates. 65
Table 17. 2002 density estimates for monitoring strata and recovery units. 66
Table 18. 2003 estimates of encounter rates, proportion of tortoises that were visible, and detection rates. 67
Table 19. 2003 density estimates for monitoring strata and recovery units. 68
Table 20. 2004 estimates for encounter rates, proportion of tortoises that were visible, and detection rates. 69
Table 21. 2004 density estimates for monitoring strata and recovery units. 70
Table 22. 2005 estimation of encounter rates, proportion of tortoises that were visible, and detection rates. 71
Table 23. 2005 density estimates for monitoring strata and recovery units. 72
Table 24. Comparison of original density estimates (USFWS 2006) with corrected estimates in this report. 74

LIST OF FIGURES

Figure 1. Range of tortoises in the Mojave population (USFWS 1994). Monitoring strata fall within recovery units. For 2007 only, the Newberry Springs and Pinto Mountains 2 strata were surveyed along with the long-term monitoring strata. 11
Figure 2. Relationship between single-observer detections (by the leader) and dual-observer (team) detections. 19
Figure 3. Process for developing density estimates in 2007. For each type of estimate needed, the full set of data was subdivided appropriately. Contributing estimates in the four left-hand columns are listed with the subsets of the data on which they are based. These estimates combined from left to right to generate stratum and recovery unit density estimates. 20
Figure 4. Detection curves for each of the 2007 trainee teams that returned after at least one year of monitoring experience. Curves are based on 16km trials. 22
Figure 5. Detection curves for each of the 2007 first-year teams that were kept together throughout training. Curves are based on 16km trials. 22
Figure 6. Distribution of distance sampling transects and live tortoise observations in the Coyote Springs Valley, Mormon Mesa, Beaver Dam Slope, and Gold Butte-Pakoon monitoring strata. 28
Figure 7. Distribution of distance sampling transects and live tortoise observations in the Piute-Eldorado Valleys, Ivanpah, Fenner, and Chemehuevi monitoring strata. 29
Figure 8. Distribution of distance sampling transects and live tortoise observations in the Fremont-Kramer, Superior-Cronese, Ord-Rodman, and Newberry Springs monitoring strata 30
Figure 9. Distribution of distance sampling transects and live tortoise observations in the Pinto Mountains, Pinto Mountains 2, Joshua Tree National Park, Chuckwalla, and Chocolate Mountain AGR monitoring strata. 31
Figure 10. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by Kiva. Observations were truncated at 12m. 33
Figure 11. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by GBI. Observations were truncated at 12m. 34
Figure 12. Behavior of detection on the line by the leader (*p*) and by the team (*g(0)*) based on all observations out to a given distance from the centerline in 2007. Note convergence of *g(0)* on 1.0 at the transect line (at distance=0). 36
Figure 13. Estimates of *g(0)* based on smaller and smaller intervals of data around the transect centerline. The curves approach *g(0)* = 1 as the interval gets smaller. Curves are plotted for the 3 years when the dual-observer method was used. 37

ACKNOWLEDGEMENTS

Suggestions and considerations for the design of this project were first set out in Anderson and Burnham (1996); this paper has continued to guide improvements to the project as new data update our understanding of desert tortoises. S. Buckland, L. Thomas, T. Marques, E. Rexstad, and D. Harris conducted a 2008 workshop for distance sampling in Marshall, California. Their general instruction and specific input during the analysis for this report were invaluable. C. Overton and J. Yee (USGS) reviewed the specific design that was implemented in 2007, using systematically spaced transects, anchored at random on the monitoring strata.

R. Scofield (U.S. Department of Interior) and C. Everly (U.S. Department of Defense) coordinated support by land managers (state and federal agencies, including military installations) in the Desert Managers Group for sampling in California. Funding or support-in-kind was provided by Edwards Air Force Base; Fort Irwin National Training Center; the Marine Corps Air Ground Combat Center; the Marine Corps Air Station, Yuma; Joshua Tree National Park; Clark County, Nevada, Desert Conservation Program; the California Desert Division of the Bureau of Land Management; and the Arizona Strip Office of the Bureau of Land Management. F. Getz (General Services Administration) assisted with contracting work in California.

R. Patil (University of Nevada, Reno) updated the Ruggedized Data Assistant (RDA) data-collection forms and procedures used in 2007. Personnel from Kiva Biological Consulting (California) led by K. Wright and from the Great Basin Institute (Nevada, Arizona, and the Beaver Dam Slope of Utah) led by P. Kahn conducted the field surveys. I acknowledge the hard work of all the field monitors who collected data: L. Backus, E. Bonhett, G. Botello, J. Brouwer, M. Brouwer, A. Croisant, R. DePond, J. Dushane, T. Embrey, D. Focardi, M. Gallagher, T. Graham, N. Grenier, S. Harris, B. Hasskamp, M. Hasskamp, S. Jones, C. Keaton, K. Kermoian, P. Kermoian, C. Kuntzsch, M. MacIntosh, T. Manney, A. Padilla, L. Pavliscak, R. Saltmarsh, P. Seamount, J. Sonn, C. Spake, T. Thigpen, R. Vaghini, K. Weeks, J. Weidensee, R. Williamson, J. Wilson, S. Wong, K. Wright, J. Wright, J. Young, and S. Zimnavoda.

S. Corn, P. Medica, and K. Nussear (USGS); and E. Aldrich, J. Heaton, and R. Marlow (University of Nevada, Reno), provided training for field crews. C. Everly (Mojave Desert Ecosystem Program) provided independent quality control for data submitted by both field groups, and developed initial GIS products. M. Brenneman provided quality assurance steps leading to final spatial and non-spatial databases.

C. Darst (USFWS) and M. Connor (Western Watersheds Project) each provided very useful, very thorough reviews of an earlier draft of this report.

EXECUTIVE SUMMARY

The recovery program for the Mojave population of the desert tortoise requires range-wide, long-term monitoring to determine whether recovery goals are met. Specifically, will population trends within recovery units remain stable for a period of 25 years? In 1999, the Desert Tortoise Management Oversight Group endorsed the use of line distance sampling (Buckland et al., 2001) as the method for estimating range-wide desert tortoise density. From 2001 to 2005, and again in 2007, desert tortoise populations in 5 of the 6 recovery units have been part of a coordinated, range-wide monitoring program using line distance sampling. (The Upper Virgin River Recovery Unit is monitored by Utah Division of Wildlife Resources.) The first 5 years of monitoring culminated in a summary report (USFWS, 2006) that included eleven recommendations, seven of which were tied to functioning of the monitoring program and are paraphrased here:

1. The range-wide monitoring program should continue under a formal study plan subject to scientific review.
2. Refine [line distance sampling] techniques to improve sampling efficiency and estimates of trends.
3. Evaluate the spatial scale of the monitoring program.
4. Improve training lines.
5. Evaluate the use of independent field teams in order to improve data consistency and quality.
6. Refine and formalize/document the QA/QC process.
7. Identify and assess options for securing continued funding for range-wide population monitoring.

When monitoring started again in 2007, the following steps were taken to implement these recommendations (numbers correspond to the recommendations above):

1. Parts of the original study plan (Anderson and Burnham, 1996) that had not been implemented originally were put in place. The resulting system for placement of transects under this plan was reviewed by spatial analysts with USGS.
2. Five sub-recommendations were made and three implemented within the program:
    a. Individual monitoring strata were used to stratify reanalysis of the 2001 to 2005 monitoring data. They were also used as recommended in Anderson and Burnham to stratify transect placement in 2007. The number of transects in each stratum was adjusted to target desired precision, based on 2001-2005 density estimates and as described in the original study plan.
    b. Estimates of detection probability were modified to reflect a balanced level of effort between teams. This approach to developing robust estimates has been published and implemented elsewhere. Examination of telemetry data was used to

identify the consistent optimal monitoring period (April-May) when tortoises are predictably visible. This informed timing of monitoring in 2007 and selection of data to reanalyze from 2001 to 2005.

   c. A white paper was generated to guide the approach for estimating G_0 in 2007.

3. Data were collected for each assigned transect, describing access and completion issues so these can be addressed when the same transects are repeated in the future. Procedures were implemented to allow completion of transects in a non-standard way so that unsampled areas from earlier years could be surveyed.
4. Steps for improving training were taken in 2008, after the period of this report.
5. A second monitoring organization was contracted to provide field crews in 2007. Previous to this, some crews had organizational oversight, while others were contracted through a national hiring center, with all oversight and responsibility on the project planners.
6. The 2007 data management plan was drafted for the first time before the field season started.
7. No steps were taken to ensure stabilized funding for the annual monitoring effort.

This report describes the full set of quality assurance steps and final results for the 2007 monitoring effort. In 2007, the range-wide monitoring effort was partitioned among 17 sampling strata based primarily on critical habitat/Desert Wildlife Management Area/Area of Critical Environmental Concern boundaries. Data were collected by 20 field teams working with two different groups, Kiva Biological and Great Basin Institute. After an intensive, 1-week specialized training session, crews completed 557 transect surveys between 1 April and 20 May. In the course of these surveys, they walked 5936 kilometers of transects and reported 251 live tortoises.

Training is provided each year so that field crews are familiar with the specifics of distance sampling. Training also ensures consistency between the many crews collecting data. Inexperienced crews as well as those with prior experience participated in preseason training and testing provided by the University of Nevada, Reno, and by the U.S. Geological Survey. Inexperienced crews began training two weeks before the more specialized training was provided to the larger group. All of the experienced 2-person teams provided appropriate detection curves, detection proportion on the transect line, measurement accuracy from tortoise models to the transect line, and proportion detected by the leader and the “clean up” follower on the team. After training, it was determined that inexperienced crews averaged fewer tortoise models on the testing lines and were less precise in their distance measurements, so these skills will be a target of future training. Detection curves for each team were subjected to real-time evaluation in 2007, and on this basis, 8 of the 13 inexperienced teams were rebuilt with new pairings during training.

Four parameter estimates contribute to final reported tortoise densities in each monitoring stratum. The basis for distance sampling is the estimation of the number of tortoises detected at increasing distances from the walked transect. As the surveyors look farther from the transect centerline, they will detect fewer and fewer of the tortoises that are actually there, so describing the way detections decrease with distance allows for estimation of the proportion that were present but not detected within a given distance of the transect centerline. Second, an estimate is made of the proportion above ground or visible in their burrows and available to be detected on transects. Third, the first two estimates are combined with the number of tortoises encountered per kilometer walked to provide the actual density in each stratum. Finally, the proportion detected on the line must be estimated. Unless all tortoises were detected on the centerline, the density estimate must be adjusted to account for the occurrence of these additional tortoises.

In 2007, Kiva crews detected 49% of tortoises within 12m of the transect centerline, GBI detected 61%. The proportion of tortoises that were visible to be counted (G_0) varied in different parts of the range, which were also surveyed at different times during the spring season. Visibility varied from a high of 97% in MCAGCC during the second week in April to 77% at the Coyote Springs telemetry site, monitored during the last month of the field season. On average, crews walked 24km for each tortoise that was observed, but this number varied considerably from one monitoring stratum to the next. As usual, strata in the Northeastern Mojave Recovery Unit had the lowest densities (1.2 per km^2 in both the Gold Butte-Pakoon and the Beaver Dam Slope strata). The highest densities was reported on the Chocolate Mountain Air Gunnery Range (7.1 tortoises per km^2) and in the Ord-Rodman critical habitat unit (8.2 tortoises per km^2).

A priority for 2007 was to improve precision of density estimates. One large source of variance in density estimates has been the estimation of G_0. Analysis before the field season started indicated that much of the day-to-day variance in G_0 is due to monitoring over large spatial scales (where factors affecting tortoise activity may vary considerably) and over relatively large temporal scales (entire spring activity seasons) that describe activity over a period when the phenology of annual food plants changes considerably and when diurnal temperatures increase markedly.

For 2007, the study design was changed to minimize the variance of G_0. Each of six groups of telemetry sites and neighboring transect strata were completed in sequence to minimize the number of days required in the neighborhood of a given group and to more closely reflect only local conditions. Comparison of the 2005 with 2007 estimates of G_0 shows that in two of seven telemetry sites that were used both years, the precision of the estimate did not improve when fewer days were monitored, but the overall pattern indicates that this strategy will help improve the precision of the resulting density estimates. The method for calculating the variance of G_0 was also corrected this year.

By moving the final steps of the analysis out of Program DISTANCE, in 2007 I was able to utilize these regional estimates for G_0 as well as provide stratum-level density estimates. In many areas of the range in 2001 to 2005, a similar grouping approach had been used, completing local transects and monitoring telemetry sites in a short period of time. However, the previous method of analyzing data could only accommodate one G_0 estimate per year.

Estimates of density for 2007 are lower for all recovery units than the revised or original estimates for 2005. This change coincides with increasing efforts to sample from all of the areas managed for desert tortoises; the new areas of interest were excluded in the past as potentially low or no suitability to desert tortoises. Even if no change has occurred in population numbers, it is expected that estimates of overall tortoise densities will be lower if many of the areas added to the sampling frame contain lower densities of tortoises than the core areas sampled among all years.

To enable field crews to complete transects in some of these previously unsampled areas, a set of guidelines were developed at the beginning of the field season for completing transects in areas with rugged terrain or other obstacles (Appendix A). These rules did enable crews to sample entire strata in a more representative way; however, based on site visits with crews and visual (GIS) inspection of how these rules were applied on specific transects, guidelines were not applied consistently. During end-of-season debriefings, crew feedback also underscored that the rules were difficult to apply. A much-simplified, intensively instructed protocol for non-standard situations was developed for future years beginning in 2008.

Finally, the success of the range-wide monitoring program also depends on developing reliable, adequate, and consistent funding. Reanalysis of data from 2001 through 2005 clearly illustrated that sufficient effort (transects) in each stratum is needed to encounter several tortoises, otherwise estimates are not possible. In 2002, 2003, and 2004, sampling effort in one or more strata was insufficient to estimate density in at least one recovery unit. Effective implementation of this program requires stable funding so that monitoring effort matches planning requirements rather than funding limitations.

RANGE-WIDE DESERT TORTOISE POPULATION MONITORING 2007

INTRODUCTION

The Mojave Desert population of the desert tortoise (*Gopherus agassizii*) was listed as threatened under the Endangered Species Act in 1990. The initial recovery plan (USFWS, 1994) designated six recovery units to which decisions about continued listing should be applied. Both the 1994 recovery plan and the draft revised recovery plan (USFWS, 2008) specify that consideration of delisting should only proceed when population trends in each recovery unit are stable or increasing for at least one tortoise generation (25 years), and the only means to determine trend is by a rigorous program of long-term monitoring. Before the tortoise was listed, populations were monitored either using strip transects (Luckenbach, 1982) where indications of tortoise presence (live or dead tortoises, scats, burrows, or tracks) were converted to estimates of abundance based on transects conducted in areas of better-known tortoise density, or by using capture-recapture population estimates on a limited number of (usually) 1-mi^2 study plots (Berry, 1984). Although data have continued to be collected on transects and study plots in recent years, both methods suffer statistical deficiencies and logistical constraints that render them unsuited for monitoring trends in abundance applicable either range-wide or to individual recovery units (Corn, 1994; Anderson et al., 2001; Tracy et al., 2004). In 1999 the Desert Tortoise Management Oversight Group endorsed the use of line distance sampling (Buckland et al., 2001) for estimating range-wide desert tortoise density.

Distance sampling methods use measurements taken from the center of the transect lines to tortoises to model detection as a function of distance from the walked path; tortoises farther from the travelled path have a lower probability of detection. In order to anchor the curve and estimate the number of tortoises within a given distance from the center of the transect, the assumption is applied that all tortoises are detected on the transect center line (Anderson et al., 2001; Buckland et al., 2001). There are minimal additional assumptions in distance analysis – that distance is measured to the point where the animal was first detected and that distance is measured accurately – but these are easily satisfied in line distance sampling of desert tortoises. The assumption that detection at the center line of the transect is perfect, however, can be violated during line distance sampling of tortoises, but the use of two observers minimizes these violations of the assumption and provides a correction factor in the form of an estimate of the number of tortoises on the line that were missed (USFWS, 2006).

Distance methods have been used to estimate abundance of Desert Tortoises in the Sonoran Desert in Arizona (Swann et al., 2002; Averill-Murray and Averill-Murray, 2005) and in the Upper Virgin River Recovery Unit in Utah since 1998 (McLuckie et al., 2008). The USFWS used line distance sampling to estimate abundance of tortoises in the remaining five recovery units in Utah, Arizona, Nevada, and California starting in 2001 (USFWS, 2006). This report

includes further evaluation of data from the first 5 years of the study, describes the sampling design adopted for 2007 to address some of these results, reports on the results of training exercises for field crews, presents the analysis of desert tortoise density in 2007, and uses the refined approaches to reanalyze data from 2001 through 2005.

METHODS

Study areas and transect locations

Long-term monitoring strata will be used over the life of the project to describe population trends in areas managed to conserve tortoises. Figure 1 depicts these strata as well as 2 more that were added for 2007 only. Strata were created for Newberry Springs and Pinto Mountains 2 to create density estimates for relatively large contiguous areas of public land located near other areas managed for desert tortoises. Density estimates for these single-year strata are not included in annual recovery-unit-level estimates that are assessed for long-term trends.

Modification of previous procedures

Monitoring strata encompass large areas with variable geography and topography. It is expected that tortoises will not occupy any one stratum at a uniform density; some local areas will support higher numbers of tortoises than others. In addition, some of the terrain is so rugged that it would not be safe to complete transects there. From 2001 to 2003, these considerations led planners to mask out some areas of each stratum from sampling (USFWS, 2006). The excluded areas changed in each of these years, however, and for purposes of estimating densities in these strata, more extensive and consistent sampling was desirable. In 2004 and 2005, transects were placed at random on the landscape, with crews able to remove or "slide" transects based on safety considerations (USFWS, 2006). Examination of completed transects after the field season indicated that local areas had not been sampled and many transects were moved for reasons that were unclear – in part because field crews had not documented their decision-making process.

In 2007, standard 12-km transects were walked using the same protocols as in 2004 and 2005 (USFWS, 2006), with up to 25% alternate transects provided to replace any unwalkable assigned transects. A new set of guidelines were provided to crews to give them options for completing transects without moving them away from the basic assigned location; from 2004 and 2005, crews were instructed in how to move transects to areas more likely to hold tortoises and/or areas that were less difficult for humans to traverse. The 2007 guidelines (Appendix A) were developed after training to set conditions under which non-standard transects would be created by 1) deflecting transects inward, or 2) creating rectangular transects along obstacles associated with human infrastructure (large roads, private inholdings, etc.). In rugged terrain, 3) transects could be shortened to enable completion before 4pm each day.

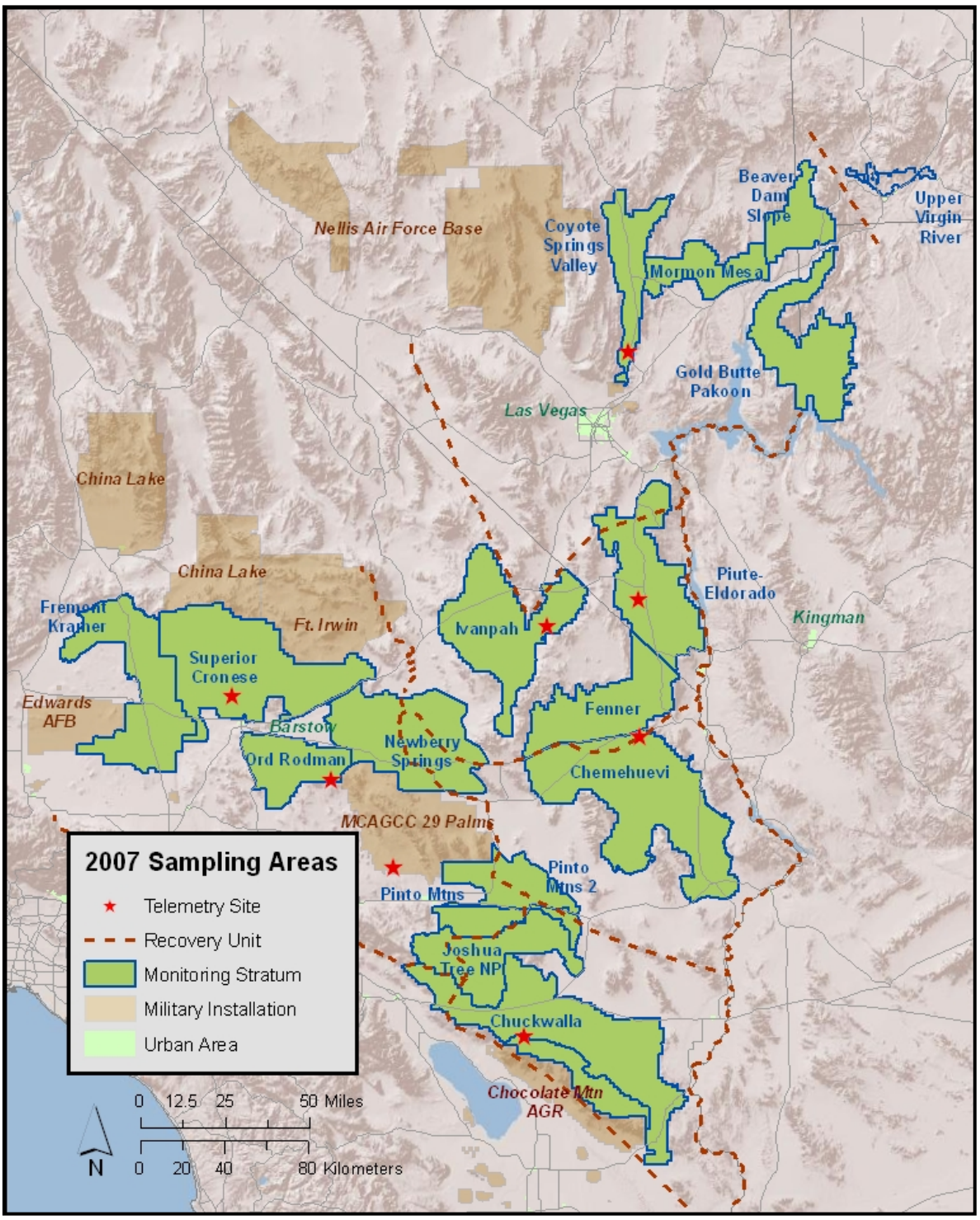


Figure 1. Range of tortoises in the Mojave population (USFWS 1994). Monitoring strata fall within recovery units. For 2007 only, the Newberry Springs and Pinto Mountains 2 strata were surveyed along with the long-term monitoring strata.

The optimal number of transects in a monitoring stratum was determined by evaluating how these samples would contribute to the precision of the annual density estimate for a given recovery unit. Anderson and Burnham (1996) prepared a power analysis to guide this sort of evaluation for the long-term desert tortoise monitoring project. The power to detect an increasing population size is a function of 1) the magnitude of the increasing trend, 2) the "background noise" against which the trend operates, and 3) the length of time the trend is followed (even a small annual population increase will result in a noticeably larger population size if the increase continues for many years). Using readily accessible software (TRENDS; Gerrodette, 1987), Anderson and Burnham (1996) considered a number of possible scenarios (Table 1).

Table 1. Scenarios explored in Anderson and Burnham (1996) and associated power for a one-tailed test.

Actual annual change in abundance	CV	α	Years between first and last survey	Years between consecutive surveys	Power
-0.12	0.15	0.15	4	1	0.78
-0.12	0.15	0.15	5	1	0.97
+0.02	0.15	0.15	25	1	1.00
+0.01	0.15	0.15	25	1	0.86
+0.02	0.35	0.15	25	1	0.72
+0.02	0.15	0.15	25	2	0.99
+0.02	0.15	0.15	25	3	0.92
+0.02	0.15	0.15	25	4	0.83

The magnitude of the population trend is a function of recovery activities and the population dynamics of the tortoise – neither of these elements are affected by monitoring design and sample size. The second contributor to the power to detect a trend – the level of background variability in the density estimates – is directly affected by the number, length, and placement of transects in the monitoring strata. Anderson and Burnham (1996) recommended that transect number and length be assigned to target precision reflected in a coefficient of variation (CV) of 10-15% for the estimate of importance. The CV describes the standard deviation (a measure of variability) as a proportion of the mean. It is often converted to a percentage. Since recovery criteria target trends within recovery units (USFWS, 1994), precision in that density estimate was the focus. The target CV is achieved based on the number of tortoises that might be encountered there (some strata currently have higher densities than others), as well as the area of

the stratum – its proportional contribution to the recovery unit density estimate (Buckland et al., 2001).

The actual number of transects assigned in each stratum was a function of the optimal numbers described above, as well as on available funding. Even in cases where funding was not directly available from the associated land management agency, a smaller number of transects were nonetheless placed in each long-term monitoring stratum so that year-to-year recovery unit estimates would be based on the same monitoring areas. This approach to optimizing transect numbers in each stratum differed from that in previous years, when transects numbers were assigned in proportion to sample area, and strata without dedicated funding were not sampled.

Once the number of transects in a stratum was determined, these were laid out systematically across strata, with a random origin for the lattice that separated the transects. In strata with more transects, nested lattices with smaller spacing (3km) were used to ensure sufficient transects. In strata with fewer transects, lattices with wider spacing (9- or 27-km spacing) were used. Use of systematic placement provided more even coverage of the entire stratum, something that may not occur when a strictly random placement of transects is used. In both cases, transects are located at random with respect to the location of desert tortoises.

Systematic placement of transects was recommended by Anderson and Burnham (1996) but had not been used in previous years. In those years, strictly random placement of transects was adopted.

Field observer training

In 2007, two sets of field observers participated. Kiva Biological (Kiva) supplied crews for monitoring in California. Great Basin Institute (GBI) supplied crews for monitoring in Nevada, Arizona, and Utah. The former crew was composed almost entirely of teams with previous years of experience, whereas the latter crew had only one experienced member. The GBI crews were therefore provided with 2 weeks of preparatory training before a single week of joint training with the experienced Kiva crew (Table 2). The goal of the final (joint) week was to standardize the protocols used by crews range-wide. A single evaluation was given to each paired team, based on performance on a field arena outfitted with a high density of polystyrene tortoise models placed in measured locations (Anderson et al., 2001). Crews were evaluated on 1) ability to detect all tortoises within 1m of the centerline, 2) shape of the team's detection function indicating appropriate search technique, 3) leader detecting close to 80% of the tortoise models (related to above requirement for the pair to detect all tortoises on the centerline), and 4) ability to correctly report the distance of each model from the transect centerline.

In 2008, UNR was contracted through USFWS and Clark County, Nevada, to provide not only the specialized line distance sampling training, but also training to bridge the gap between a general biology education and the specialized skills needed for line distance sampling (March 12 to 22).

Table 2. Training schedule for 2007

Date[a]	Activity	Location[b]	Trainer(s)
Monday, 12 March	Tortoise handling in small groups Developing tortoise search image	DTCC	Marlow (UNR), Nussear (USGS), Medica (USGS)
Tuesday, 13 March	--		
Wednesday, 14 March	Compass and pacing exercise	LSTS	Marlow, Nussear, Medica
Thursday, 15 March	Practice transects (start with 400m, end with 12km)	LSTS	Marlow, Nussear, Medica
Friday, 16 March			
Monday, 19 March	Practice transects	LSTS	Kahn (GBI)
Tuesday, 20 March	Tortoise handling in small groups	Field station	Marlow, Medica
	Transect Methods Lecture (incl. data collection)	Field station	Kipke (NDOW)
Wednesday, 21 March	Practice transects – teams of 5, with electronic and paper data collection	LSTS	Medica, Kahn
Thursday, 22 March			
Monday, 26 March	Desert Tortoise Recovery & Monitoring Program	USGS	Allison (FWS)
	Introduction to Line Distance Sampling		Corn (USGS)
	Tortoise natural history		Woodman (Kiva)
	Electronic data collection forms		Heaton (UNR)
	Preparation for training lines		Corn
Tuesday, 27 March	Training Lines (evaluation, 8km) RDA data download	LSTS	Corn/Heaton
Wednesday, 28 March	Training Lines (evaluation, 8km) RDA data download	LSTS	Corn
Thursday 29 March	Practice transects (8km)	LSTS	
Friday, 30 March	Training line debriefing Quality control feedback on training data	USGS	Corn Heaton
Monday, 2 April	Training Lines (evaluation, 8km)	LSTS	

[a] The first two weeks were attended by inexperienced (GBI) field crews; the final week provided joint training for GBI and Kiva crews with previous experience at desert tortoise line distance sampling.

[b] Locations: DTCC=Desert Tortoise Conservation Center, Las Vegas; LSTS=Large Scale Translocation Site near Jean, NV; Field Station=facility maintained by UNR in Henderson, NV; USGS=USGS Henderson, NV facility

Proportion of tortoises detected at varying distances from the transect centerline
Polystyrene models of desert tortoises ("models") are placed on the training course using the same placement instructions (vegetation or open placement, distance along training line, and distance perpendicular from training line) each year. This course is used to determine whether 1) individual teams are able to detect all models on the transect center line, 2) whether their survey techniques yield useful detection functions, and 3) whether they can accurately report the distance of each model from the transect centerline. For each purpose, many opportunities must be provided, so the course is populated at a very high density of models (410/km^2).

Crews are sent on transects and training lines as paired, independent observers. That is, the follower is 25m behind the leader, with the opportunity to detect models not found by the leader. If the leader detects 80% of all tortoises that are found, the assumption is that the follower detects 80% of the tortoises that are missed by the leader. If this assumption is true, in this example, the pair together will detect 0.80 + (0.80 X (1 – 0.80)) = 0.96 of all tortoises on the center line. Because the location of all models is known, data from training lines can also be used to 1) assess the dual-observer assumption that all models are equally detectable (detections attributed to the follower occur at the same rate as original detection rate by leader), and 2) to estimate the detection rate using this technique for tortoises elsewhere in the Mojave Desert.

Tortoise encounter rate and development of detection functions
The number of tortoises seen in each stratum and their distances from the line are used to estimate the encounter rate (tortoises seen per kilometer walked), the detection rate (proportion of available tortoises that are detected out to a certain distance from the transect centerline), and their respective variances. Detection function estimation is "pooling robust" under most conditions (Buckland et al., 2001). This property holds as long as factors that cause variability in the curve shape are represented proportionately (Marques et al., 2007). Factors that can affect curve shape include vegetation that differentially obscures vision with distance, or different detection protocols used by individual crews. All crews in the California crew (Kiva in 2007) walked the same number of transects (days), and all crews in Nevada/Arizona/Utah (GBI in 2007) also had equal effort, but funding differences for the two associated parts of the tortoise range resulted in more transects per team (more effort) for GBI. For this reason, I estimated detection functions separately for GBI- and Kiva-monitored strata. The encounter rate is much less sensitive to small sample sizes, so it was estimated for each stratum separately.

I used Program DISTANCE, Version 5, Release 2 (Thomas et al., 2006) to fit appropriate detection functions, to estimate the encounter rate of tortoises in each stratum, and to calculate the associated variances. One record was created for each transect, with additional records for each additional tortoise on that transect. Analysis was only applied to live tortoises with midline carapace length (MCL) greater than 180mm. Transects were packaged into monitoring strata ("regions" in Program DISTANCE).

I truncated observations to improve model fit as judged by the simplicity (reasonableness) of the resulting detection function estimate (Buckland et al., 2001). Using truncated data, I used the Akaike Information Criterion (AIC) to compare detection-function models (uniform, half normal, and hazard-rate) and key function/series expansions (none, cosine, simple polynomial, hermite polynomial) recommended in Buckland et al. (2001).

Proportion of tortoises that are available for detection by line distance sampling, G_0

Not all tortoises in a population can be detected on transects, even if they are on the center of the transect line. Typically, these are either undetectable in deep burrows or well hidden in dense vegetation. The existence of a portion of the population that is "invisible" to sampling will bias downward the density estimates derived from line distance sampling, but if the proportion of the population available for sampling can be estimated, then this parameter (G_0) can be used to correct the bias. Estimation of G_0 was conducted using focal tortoises in 10 sites located throughout the monitoring area (Fig. 1). At these telemetry sites, the focal animals are equipped with radio transmitters and observed daily while transects are sampled in the associated strata.

Each time a transmittered tortoise was observed, it was determined if the tortoise would have been visible to an observer conducting a line transect (yes or no). Through careful coordination, observers at telemetry sites monitored visibility during the same time period when field crews were walking transects. After visiting all of the focal animals one time, observers visited focal animals as many times as possible during the allotted time, recording visibility each time. Bootstrapped estimates of G_0 started by selecting one visibility record at random for each day that a tortoise was seen. The average visibility of all tortoise observations at a site on a given day was calculated and used to estimate the mean and variance of G_0 at that site. When there was more than one site in a given area, G_0 statistics were calculated for each G_0 group of sites as the grand mean of all G_0 sites in the group. One thousand bootstrap samples were generated in SPSS (release 16.0.2; SPSS, 2008) to estimate G_0 and its standard error.

Modification of previous procedures

Density estimates are based on 3 other estimates, each with their own variance. The total variance of density is the sum of the 3 components, so the relative importance of a particular component can be estimated by its contribution to the variance of the density estimate. In analyses before 2007 (USFWS, 2006), the standard error for the estimate of G_0 was calculated to be on the order of 0.002, contributing less than 2% of the total variance in density estimates.

During planning for the 2007 field season, errors were discovered in past calculations of both G_0 and its standard error. In the past, the standard error for a given year was incorrectly adjusted by the total number of tortoises tracked that year. In USFWS (2006), it was originally estimated as:

$$SE(G_0) = \sqrt{\frac{\mathrm{var}(G_0)}{n}}$$

Where *n* was the number of tortoises that were tracked during the 2-month period. However, the standard error for describing availability of the population for monitoring should be invariant to the number of tortoises used to estimate G_0. From 2001 through 2005, approximately 100 tortoises were tracked each year, so the correct standard error should have been about ten-fold greater than the reported estimate, decreasing the precision of the density estimate:

$$SE(G_0) = \sqrt{\mathrm{var}(G_0)}$$

Further, G_0 was originally computed as the mean of all tortoise observations over all days at all sites over the field season. Using this original approach, sites with more tortoises (and tortoises with more observations) are more influential in the estimate of global tortoise activity patterns, although these sites really only provide more information for transects in the same region. The approach implemented for this report instead gives each tortoise in a site equal weight and each site is given equal weight when calculating the local G_0.

After applying the correct calculation methods, I explored the effect of this decrease in precision for the standard error of G_0 on the density estimates that had been used in 2001 through 2005 (Appendix B), and determined that G_0 estimation now contributed about 60% of the variance in density. Daily variance within sites was the most important contributor to the total variance in G_0. This is not surprising, because over the 2-month field season, conditions such as temperatures and flowering plant availability are expected to change considerably, which should result in highly variable tortoise activity.

I used these assessments to change the sampling design in 2007 so that G_0 for a given set of transects would be estimated only at the nearest G_0 site(s), and transects in the area of one G_0 group would be completed in as short a time as possible. In past years, the sampling design was also sometimes set up to provide localized visibility estimates for transects in a given area, and sometimes these transects and the telemetry site were monitored intensively and completed in a small window of time. However, even when the nearby telemetry sites were monitored on the same days as the local transects were completed, these dates were usually spread over most of the field season, interspersed with visits to other monitoring strata and their telemetry sites. The design from 2001 to 2005 reflected the intention to estimate a single representative G_0 each year.

In the process of optimizing the analysis for 2007, I also recalculated density estimates for 2001 through 2005 using separate G_0 and SE(G_0) estimates based on transmittered tortoises observed in neighboring areas on the same dates that transects were walked. The use of standard deviation uncorrected for number of tortoises observed was expected to increase the coefficient of

variation (CV) and decrease apparent precision, while the use of estimates reflecting a shorter activity period was expected to decrease CV and increase precision of the density estimate. The updated G_0 estimates, as well as stratum and recovery unit density estimates for 2001 through 2005 are provided in Appendix C. The changes from USFWS (2006) in reported density estimates for those first years of monitoring are reported in Appendix D.

Proportion of available tortoises detected on the transect centerline, *g(0)*

Transects were conducted by 2-person crews using the method adopted beginning in 2004 (USFWS, 2006). Transects were walked in a continuous fashion, with the lead crew member walking a straight line on a specified compass bearing, trailing about 25m of line, and the second crew member following at the end of the line. This technique involves little lateral movement off the transect center line, where attention is focused. Use of two observers allows "removal" type mark-recapture estimation of the proportion of tortoises detected on the line; this is a test of the assumption is that all tortoises on the transect centerline are recorded ($g(0) = 1$). The capture probability (p) for tortoises within increasing distances from the transect centerline was estimated as for a 2-pass removal estimator (White et al., 1982): p = (lead–follow)/lead, where lead = the number of tortoises first seen by the observer in the leading position and follow = the number of tortoises seen by the observer in the follower position. The corresponding proportion detected on the line by two observers was estimated by $1 - q^2$, where $q = 1 - p$. Figure 2 graphs the relationship between the single-observer detection rate (p) and the dual-observer detection rate ($g(x)$). The guideline at $g(x) = 0.9$ represents an arbitrary standard for the proportion of these cryptic animals occurring right along the transect centerline that should be detected by each team. The actual proportion detected can be estimated and adjusted for, but the target should be at least 90%. The guideline intercepts the curve, indicating that the leader should be detecting at least 70% of all tortoises on the centerline in order to meet this standard. This is the basis for one of the training metrics (see Table 3).

Few or no tortoises are located exactly on the line, and even examining a small interval – 1m on each side of the transect line – results in few observations to precisely estimate $g(0)$. Instead, my test of the assumption involves examination of the $g(0)$ estimate starting with larger intervals from the line, getting smaller and smaller. As the intervals get smaller, more observations are near the center line, so the estimates should converge on $g(0) = 1.0$.

If the test does not indicate that all tortoises were seen on the transect centerline, the variance of p can be estimated as the binomial variance = $q(1 + q)/np$ (White et al., 1982), where n = the estimated number of tortoises within 1 m of the transect centerline, and the variance of $g(0)$ is estimated as twice the variance of p.

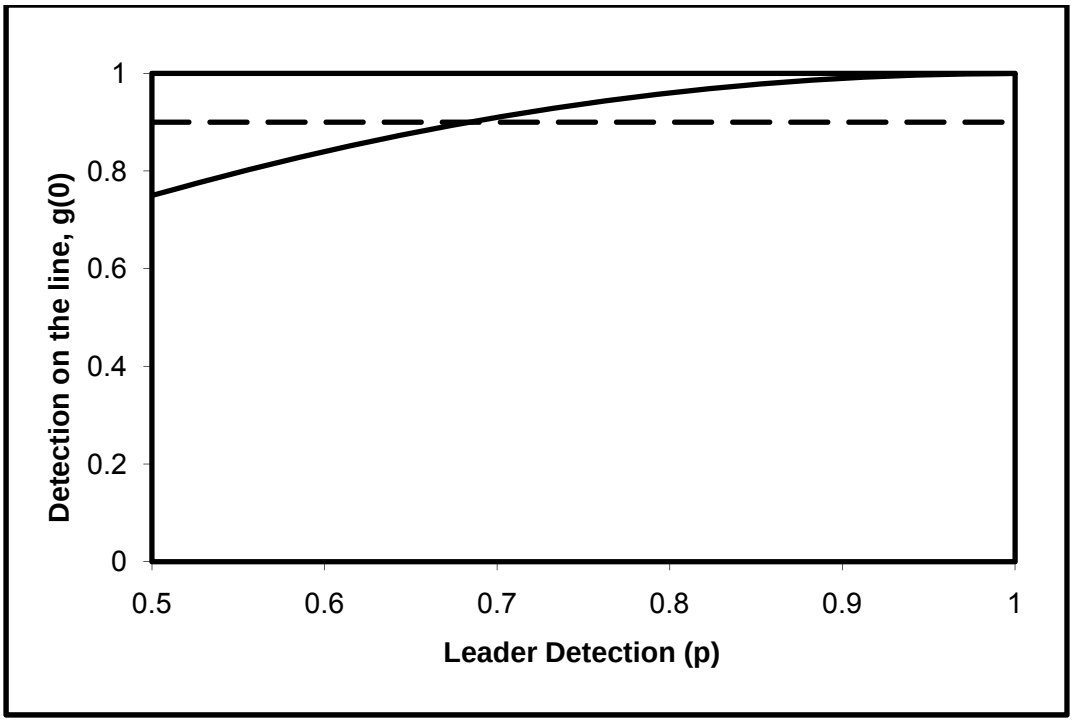


Figure 2. Relationship between single-observer detections (by the leader) and dual-observer (team) detections.

Estimates of tortoise density

Each year, the density of tortoises is estimated at the level of the recovery unit. The calculation of these densities starts with estimates of the density of tortoises in each stratum from Program DISTANCE, as well as their variance estimates:

$$D = \frac{n}{2wLP_a G_0 g(0)},$$

where L is the total length of kilometers walked in each stratum and w is the distance to which observations are truncated, so $2wL$ is the area searched in each stratum. This is a known quantity (not estimated). P_a is the proportion of desert tortoises detected within w meters of the transect centerline and was estimated using detection curves in Program DISTANCE. The encounter rate (n/L) and its variance were estimated in Program DISTANCE for each stratum. Calculation of D requires estimation of n/L, P_a, G_0, and $g(0)$. This means that the variance of D depends on the variance of these quantities as well.

For desert tortoise densities, the encounter rate (n/L) is estimated independently for each stratum ("unpooled"), whereas proportion of available tortoises and proportion of available tortoises detected on the transect center line are estimated jointly for all strata ($g(0)$) or for all strata in the recovery unit (G_0). The detection function, which comes into the above equation as P_a, may be estimated jointly or separately, depending on the number and quality of observations. In 2007,

separate detection curves were created for each field team (GBI or Kiva), pooled across all strata surveyed by that team. A schematic of the process leading to density estimates is given in Fig. 3. Density estimates for each stratum result on the right by combining the parts from the left. These stratum-level estimates can be combined to generate recovery unit density estimates, although estimates from Newberry Springs and the additional Pinto Mountains strata are not part of the long-term monitoring project and are not used to develop annual recovery-unit-level density estimates.

<table>
<tr><th>Tortoise encounter rate</th><th>Proportion that are visible, G_0</th><th>Detection rate, P_a</th><th>Proportion seen on the line, $g(0)$</th><th>Density</th><th>Density</th></tr>
<tr><td>Stratum</td><td>Neighboring G_0 sites</td><td>Data collection group</td><td>Overall</td><td>Stratum</td><td>Recovery unit</td></tr>
<tr><td>AG</td><td rowspan="2">Chuckwalla</td><td rowspan="13">Kiva</td><td rowspan="19">Full set of tortoise observations</td><td>AG</td><td rowspan="2">Eastern Colorado</td></tr>
<tr><td>CK</td><td>CK</td></tr>
<tr><td>JT</td><td rowspan="7">MCAGCC + Superior Cronese + Ord Rodman</td><td>JT</td><td rowspan="5">Western Mojave</td></tr>
<tr><td>PT</td><td>PT</td></tr>
<tr><td>FK</td><td>FK</td></tr>
<tr><td>OR</td><td>OR</td></tr>
<tr><td>SC</td><td>SC</td></tr>
<tr><td>PT2</td><td>PT2</td><td rowspan="2"></td></tr>
<tr><td>NS</td><td>NS</td></tr>
<tr><td>CM</td><td rowspan="3">Chemehuevi + Ivanpah + Piute</td><td>CM</td><td>Northern Colorado</td></tr>
<tr><td>FE</td><td>FE</td><td rowspan="3">Eastern Mojave</td></tr>
<tr><td>IV</td><td>IV</td></tr>
<tr><td>PI</td><td rowspan="6">GBI</td><td>PI</td></tr>
<tr><td>BD</td><td rowspan="4">Coyote Springs</td><td>BD</td><td rowspan="4">Northeastern Mojave</td></tr>
<tr><td>CS</td><td>CS</td></tr>
<tr><td>GB</td><td>GB</td></tr>
<tr><td>MM</td><td>MM</td></tr>
</table>

Figure 3. Process for developing density estimates in 2007. For each type of estimate needed, the full set of data was subdivided appropriately. Contributing estimates in the four left-hand columns are listed with the subsets of the data on which they are based. These estimates combined from left to right to generate stratum and recovery unit density estimates.

Whereas the number of tortoises in the set of strata representing a recovery unit can be simply added together, the variance must be arrived at by accounting for whether this involves pooled or unpooled estimates. As described above, three of the four estimates that contribute to calculating density in a stratum were based on data "pooled" from other strata as well, so when data from these strata are combined, the correlated nature of the variances has to be accounted for. Specifically, the method described in Buckland et al. (2001:89) was used to combine density variances correctly and arrive at the variance (and confidence intervals and CV) for the recovery unit. Pooled and unpooled variance estimates cannot currently be combined as needed in

Program DISTANCE, so final construction of density mean and variance estimates from the above components was completed without specialized software.

Modification of previous procedures

In previous analyses (USFWS, 2006), a single detection curve was developed for all tortoise observations range-wide. No estimate was made of the proportion of tortoises undetected on the line (*g(0)*), which was assumed to be negligible based on training data (USFWS, 2006:25) and use of the dual observer technique since 2004. A single G_0 was used, reflecting the fact that transects were completed over the entire season, so a single G_0 capturing all spatial and temporal variability was used. Finally, because stratum-level density estimates were not required, a single annual analysis was generated in Program DISTANCE, providing recovery-unit estimates of density.

To provide more appropriate detection curves (one each for GBI and Kiva), to correct density estimates using G_0 values that are more relevant to local conditions when transects were walked, and to provide stratum-level density estimates that must be correctly combined into density estimates for recovery units, the current analysis relies on Program DISTANCE for fewer steps of the process. This separation of the analysis from this software was called for in Tracy et al. (2004), and USFWS (2006) noted limitations of exclusive reliance on the software, recommending an unspecified change in procedures to allow refined analysis.

Debriefing to describe strengths and weaknesses of project preparation and execution

At the end of the field season, a debriefing meeting was held to review tasks and responsibilities, strengths and weaknesses of the program, and to plan for the next field season. Field crew members were surveyed prior to the end of the field season to identify areas to target for improvement. As a result, separate debriefings were held to address topics in data management and field season preparation.

RESULTS

Field observer training

Crew trials were conducted on 27 and 28 March (Table 2). Some first-year crews were rematched after testing to build more consistent teams and were given a further 8km trial before the field season. Figures 4 and 5 are for crews that were not rematched, and indicate well-shaped curves that nonetheless vary between crews. Strikingly different detection curves represent different detection probabilities (P_a). Detection curves that fall more rapidly after the first few meters generally indicate more appropriate search patterns, with more attention near the transect centerline. Distance sampling and development of a single detection curve from many observers is nonetheless robust to the effects of pooling these differences, as long as the observers contribute proportionally to the overall pattern (Marques et al., 2007).

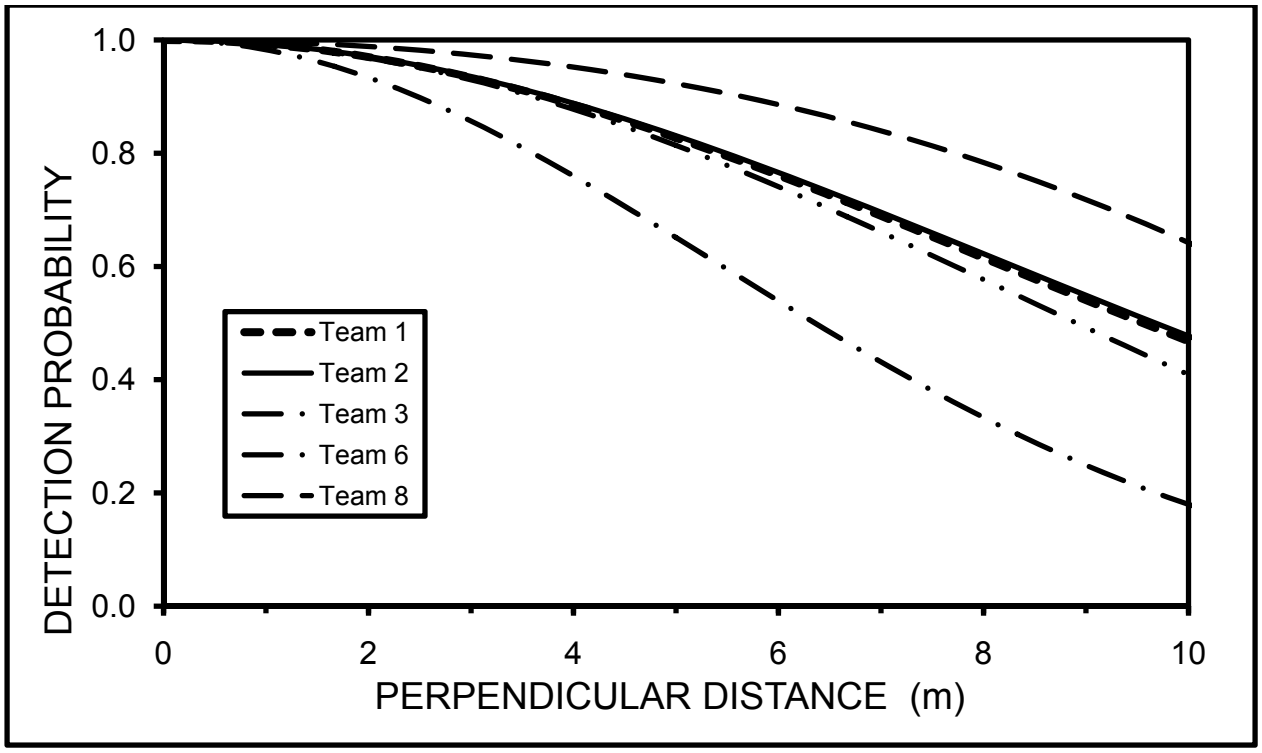


Figure 4. Detection curves for each of the 2007 trainee teams that returned after at least one year of monitoring experience. Curves are based on 16km trials.

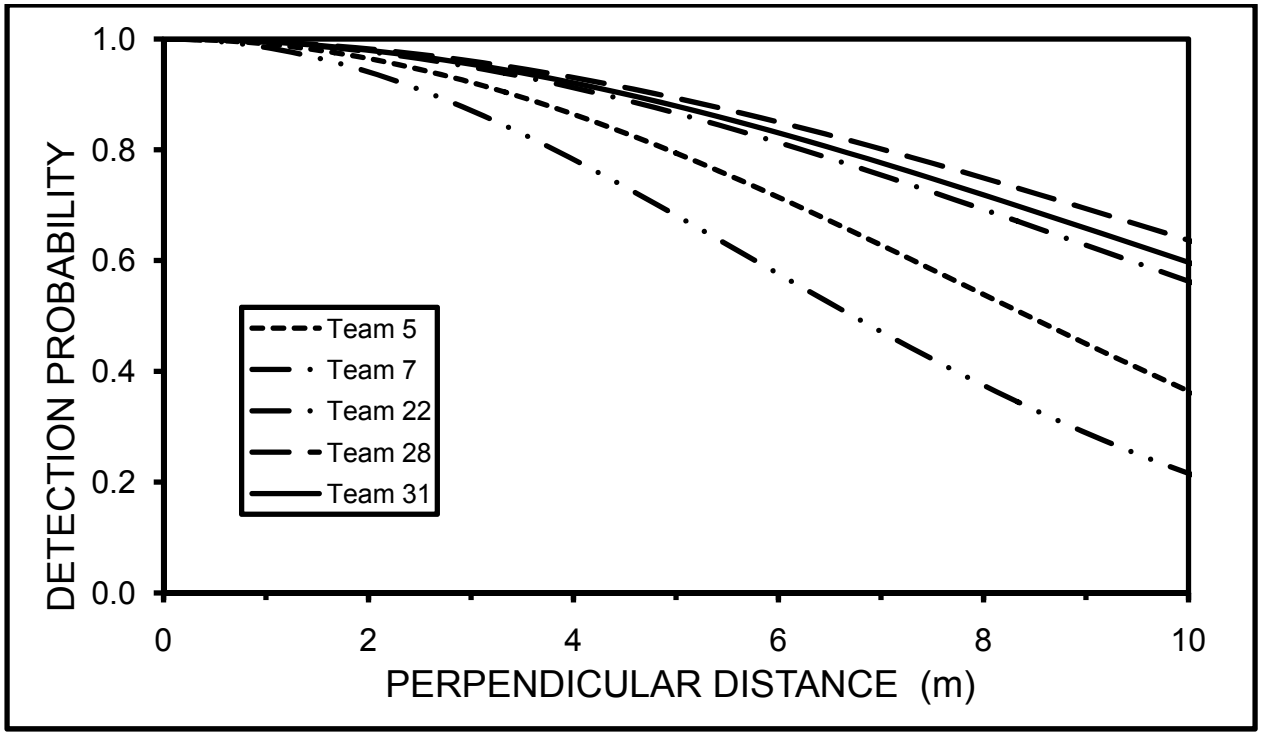


Figure 5. Detection curves for each of the 2007 first-year teams that were kept together throughout training. Curves are based on 16km trials.

Proportion of tortoises detected at varying distances from the transect centerline
Table 3 reports statistics for each team after collecting data on 16km on the evaluation lines. Measurement accuracy reported in Table 3 gives the average absolute difference between the expected and measured perpendicular distances from the model to the walked line. All measurements for all models during the 2-day trial are used for this estimate, and capture inaccuracies from 1) using a compass and measuring tape to record distances to the models, plus 2) inaccurately following the trajectory of the transect. The latter source of error does not occur on monitoring transects, because the walked transect is the true transect. On training lines, error in measurements is increased if crews do not walk on exactly the measured line that was used to place the models. The "Detected by Leader" column reports the proportion of all models found by crews that were found first by the leader. During training, this number is easily calculated and is used to identify crews in which one of the observers is not finding at least 80% of all detected

Table 3. Diagnostics for individual teams after training

Team	Detected by leader	Measured v. exact model distance (m)	Estimated abundance	95% confidence interval	
				Lower limit	Upper limit
1	0.79	0.82	415	345.2	499.4
2	0.77	0.81	398	331.7	477.4
3	0.81	1.03	485	406.5	578.8
4	0.76	0.97	359	268.3	479.1
5	0.87	1.09	386	307.9	483.9
6	0.82	0.74	394	319.4	484.9
7	0.83	0.91	415	317.3	542.9
8	0.95	0.82	410	317.6	528.7
21	0.67	1.66	320	259.4	395.4
22	0.79	1.18	314	263.6	374.4
23	0.64	0.97	312	264.1	369.7
24	0.68	1.21	442	334.2	584.5
25	0.71	1.29	296	234.7	373.3
26	0.70	1.55	445	239.0	827.0
27	0.70	1.39	316	259.6	385.3
28	0.73	2.61	389	314.8	479.6
29	0.79	0.91	401	301.4	534.8
30	0.81	0.93	282	206.9	385.4
31	0.79	1.01	386	313.5	476.2
32	0.62	1.78	269	218.8	331.1
Target	**>0.70**	**0**	**410**		
Returning crews	**0.83**	**0.84**	**420.3**		
First-year crews	**0.73**	**1.35**	**351.8**		
Overall	**0.76**	**1.18**	**371.7**		

models. With a 70% success rate for the leader, a 91% detection rate is expected for the team.After this training, in part on the basis of lower performance on detection at 1m and on "Detected by Leader," Teams 21, 23, 24, 25, 26, 27, 30, and 32 were split and new teams constructed. New teams are retested for a single day (instead of 2) to be sure they meet standards before beginning field work.

Table 4 reports the proportion of models that were available and were detected by each team at 1-, 2-, and 5-meters from the transect centerline. Teams were tested before and after the field season (pre- and post-season, respectively) and were given new team identification numbers for new pairings. Detection on the centerline was expected to be 100%, but with the returning crews

Table 4. Proportion of tortoise models detected within 1-, 2-, or 5-m of the transect center line.

	Pre-Season Detection Probabilities			Post-Season Detection Probabilities		
Team	1m	2m	5m	1m	2m	5m
1	1.00	0.84	0.84	0.67	0.75	0.75
2	0.90	0.92	0.84	0.50	0.73	0.70
3	0.90	0.88	0.90	0.67	0.75	0.72
4	0.91	0.84	0.79			
5	0.82	0.80	0.73	1.00	0.86	0.78
6	0.91	0.89	0.87	0.50	0.67	0.63
7	0.91	0.81	0.69			
8	0.82	0.77	0.71	0.67	0.75	0.66
21	1.00	0.75	0.64	0.57	0.64	0.59
22	0.69	0.79	0.68	0.25	0.36	0.50
23	0.83	0.74	0.66			
24	0.75	0.63	0.65			
25	0.75	0.62	0.63			
26	0.55	0.58	0.60			
27	0.90	0.73	0.77			
28	0.67	0.58	0.58			
29	0.82	0.83	0.77			
30	0.60	0.60	0.64			
31	0.64	0.65	0.72			
32	0.82	0.63	0.59			
33				0.75	0.36	0.41
34				0.60	0.50	0.55
35				1.00	0.77	0.70
36				1.00	0.67	0.55
Returning crews	**0.91**	**0.86**	**0.83**	**0.60**	**0.73**	**0.69**
First-year crews	**0.76**	**0.68**	**0.66**	**0.74**	**0.59**	**0.58**
Overall	**0.81**	**0.74**	**0.72**	**0.68**	**0.65**	**0.63**

averaged 91%. First-year trainees did not perform as well, and the overall average on the line was only 81% before the start of the field season. Overall averages in the final row of the table show lower detection rates after the field season than before. The basis for this is not clear, but similar results were seen in previous years. The preseason training lines are used to acclimate and evaluate teams on their overall search and detection pattern. If detection curves describing the field season effort indicate an appropriate search pattern, poor detection patterns while searching for models after the field season may reflect 1) lack of motivation, 2) acquired search pattern for live tortoises and their burrows, or 3) any number of other issues. Since the training lines with models bear only sufficient resemblance to field season transects, and the original purpose of these post-season detection curves is unclear, future effort will be directed at scrutinizing weekly data during the field season against troubling patterns rather than working on improving post-season polystyrene model detection.

Table 5 reports the observed detection rate within varying distances of the transect centerline, as well as the expected detection rate if tortoises detected by the leader and follower are seen with the same probability. Observed detection rates in the 6th column better match those in the 8th than in the 7th column, indicating that models that the first observer missed were also more likely to be missed by the second observer. Particular models were inherently more difficult to see, a violation of the assumption of equal detectability. This assumption is the basis for calculating the proportion of tortoises on the centerline that are detected during the field season, *g(0)* (see *Estimates of Tortoise Abundance*, below). The equivalent estimate on the training lines (the proportion of models within a meter of the centerline that were detected) is 0.81, but is not comparable to transect detections for many reasons. For instance, live tortoises are often detected in proximity to burrows, but no models are placed in burrows for training. The probability of detecting a burrow (leading to detection of tortoises) might also be different from the probability of detecting a tortoise on the surface, so the general concern that detection probabilities are likely to be heterogeneous will lead to future examination of factors that influence heterogeneous detection walking actual transects. These factors may affect detection on the surface as well as detection of burrows (Krzysik, 2002).

Table 5 also reports the proportion of models detected each year within 5m of the transect centerline by the leader only (column 5). This number is relatively consistent between years (mean=0.63, variance=0.011), and is one approximation of the proportion of tortoises that are expected to be found using a centerline-scanning approach to detect tortoises.

Table 5. Proportion of tortoise models that were detected by the leader (single-observer) or leader-follower team (dual-observer) following training, 2004-2007.

				Observed proportion detected		Expected proportion detected by the team[b]	
Within *x* m of centerline	Time period[a]	Year	# of Teams	Single observer (std. dev.)	Dual observer (std. dev.)	Under the assumption of equal detectability	If some models were more concealed than others[c]
1	Pre-field season	2004	20	0.63 (0.117)	0.74 (0.118)	0.86	0.74
		2005	24	0.82 (0.102)	0.90 (0.085)	0.97	0.89
		2007	20	0.72 (0.146)	0.81 (0.157)	0.92	0.81
1	Post-field season	2004	17	0.62 (0.219)	0.73 (0.216)	0.85	0.72
		2005	23	0.67 (0.181)	0.76 (0.164)	0.89	0.77
		2007	15	0.60 (0.219)	0.68 (0.220)	0.84	0.70
2	Pre-field season	2004	20	0.62 (0.110)	0.73 (0.104)	0.86	0.73
		2005	24	0.73 (0.100)	0.83 (0.085)	0.93	0.82
		2007	20	0.66 (0.140)	0.74 (0.111)	0.89	0.76
2	Post-field season	2004	17	0.62 (0.128)	0.74 (0.128)	0.86	0.73
		2005	23	0.60 (0.128)	0.7 (0.125)	0.84	0.71
		2007	15	0.56 (0.162)	0.61 (0.159)	0.80	0.67
5	Pre-field season	2004	20	0.60 (0.113)	0.73 (0.103)	0.84	0.71
		2005	24	0.67 (0.075)	0.79 (0.071)	0.89	0.77
		2007	20	0.60 (0.130)	0.72 (0.097)	0.84	0.71
5	Post-field season	2004	17	0.60 (0.136)	0.72 (0.144)	0.84	0.71
		2005	23	0.53 (0.112)	0.65 (0.101)	0.78	0.65
		2007	15	0.51 (0.129)	0.6 (0.117)	0.76	0.62

[a]Teams were tested immediately after training/before the field season, and then again after the field season.

[b]The proportion a team is expected to detect is based on the assumptions that the models are all equally detectable and the follower detects the same proportion as that leader. Based on the proportion seen by the leader (column 5), under the above assumptions, it is expected that a greater proportion of the models will be reported by the teams – note that column 7 is consistently higher than column 6. In the last column of this table, the proportion of models that are actually detectable was reduced until the expected proportion seen by the team closely matched the observed proportion (compare columns 6 and 8).

[c] The best fit between observed (column 6) and expected (column 8) occurred when it was assumed that 45% of the models overlooked by the leader were also undetectable by the follower.

Transect completion

Figures 6 through 9 show locations of transects and observations of live tortoises. Table 6 reports the number of assigned and completed transects in each stratum. The number completed in California closely approximated the planned (assigned) number (98% completion) and was purposely trimmed during the field season when all anticipated funds did not materialize. However, only 89% of transects assigned to the other field crew were completed. A small set of issues prevented completion of more transects by GBI.

The Union Pacific Railroad gated the primary access road through the center of the Mormon Mesa stratum. This action alone prevented access to 24 transects in that stratum. Identifying the shifting set of access routes characterized a larger issue for the GBI crews and was partially responsible for unwalked transects that were not in rugged terrain (last column of Table 6). The late initiation of their agreement precluded much logistic planning, and access routes were sometimes not found into parts of the monitoring strata.

The basic completion percentages do not describe the most important issue that remained to be addressed. Only a proportion of assigned transects could be completed in the planned way: a 12km square transect, 3km on a side (Table 6). Various obstacles affected transect completion. Some obstacles, such as uncrossable highways and private inholdings, could be addressed by "reflecting" the corner of the transect inward to avoid the obstacle (Buckland et al. 2001, Appendix A) or by elongating the transect in one direction. This modification was not expected to move the transect into a different landform, a change that would affect the probability of encountering tortoises on the transect. However, other obstacles were more difficult to address. The jurisdictional boundaries of the monitoring strata include terrain that may be navigable by tortoises, but is not safe for humans. However, if a transect is reflected around rugged terrain, keeping the transect in flatter topography, this is expected to impact the probability of encountering a tortoise.

From 2001 through 2003, planners for the monitoring project eliminated such areas from sampling, but each year saw changes to the filter they used, so the conclusions from the resulting data could not be compared between years or applied to the entire DWMA. In 2004 and 2005, the planners put transects out at random, but allowed field crews to "slide" transects away from such obstacles; however, this resulted in transects that were still not representative and in modifications that were not documented.

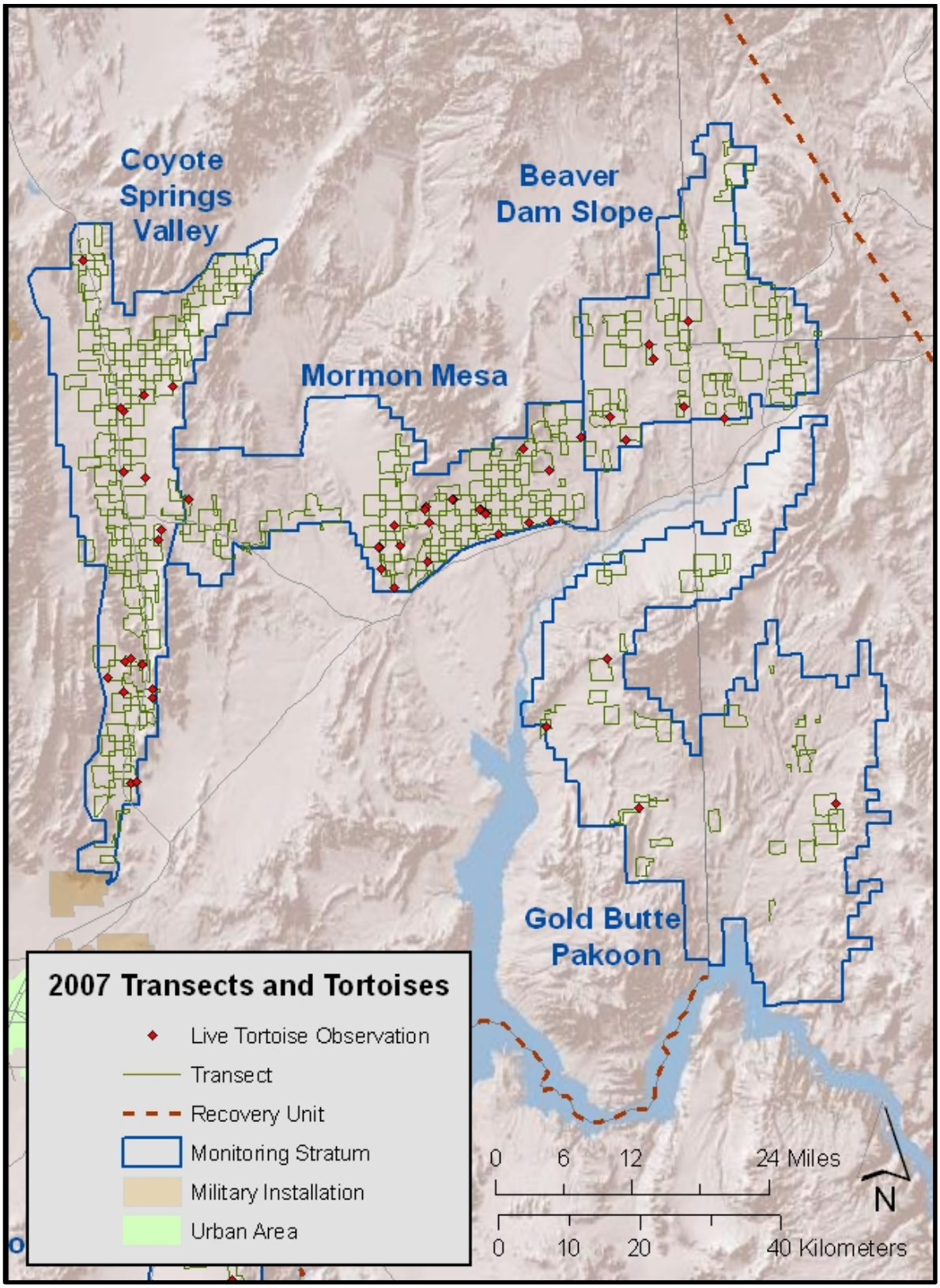


Figure 6. Distribution of distance sampling transects and live tortoise observations in the Coyote Springs Valley, Mormon Mesa, Beaver Dam Slope, and Gold Butte-Pakoon monitoring strata.

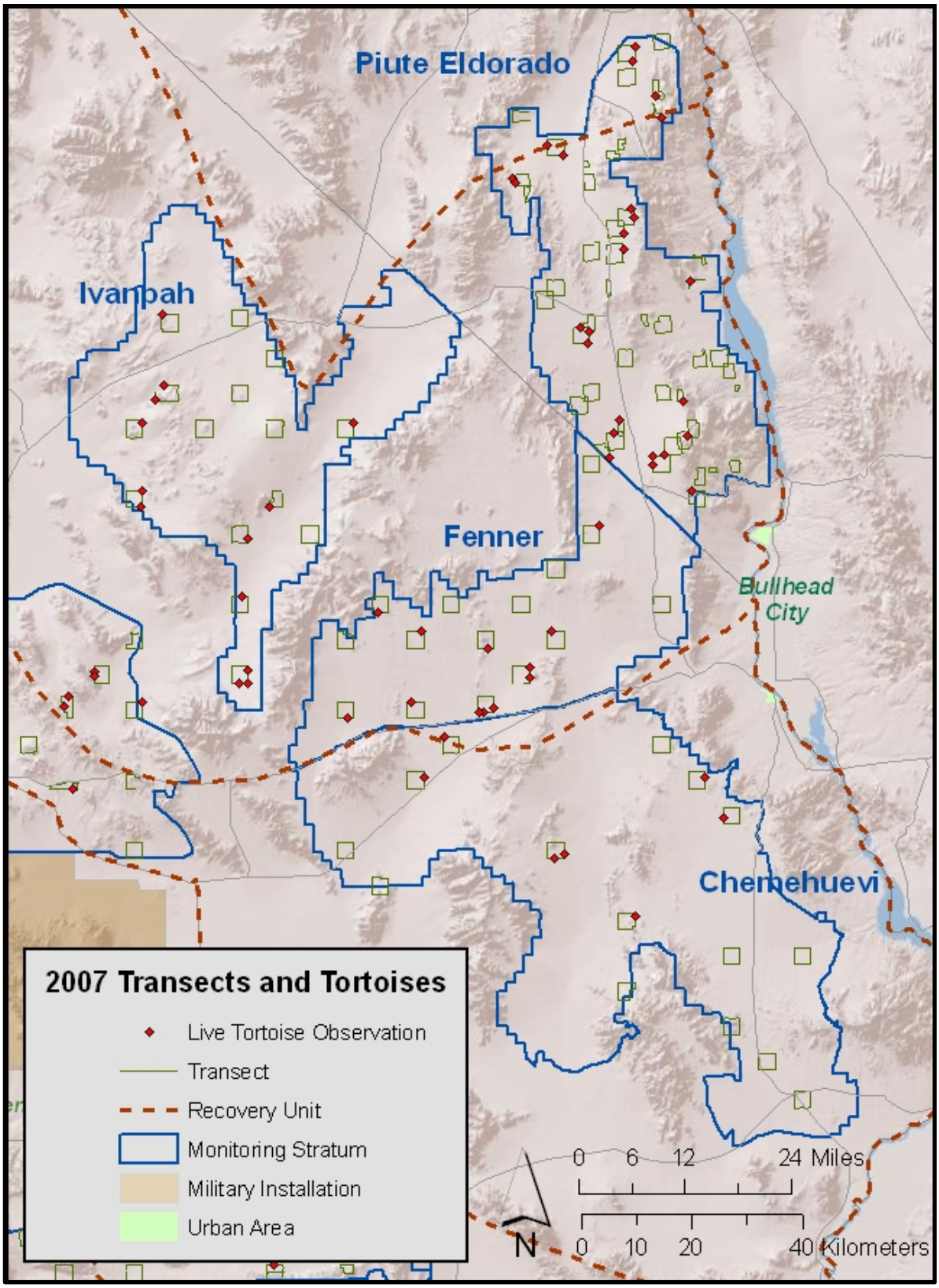


Figure 7. Distribution of distance sampling transects and live tortoise observations in the Piute-Eldorado Valleys, Ivanpah, Fenner, and Chemehuevi monitoring strata.

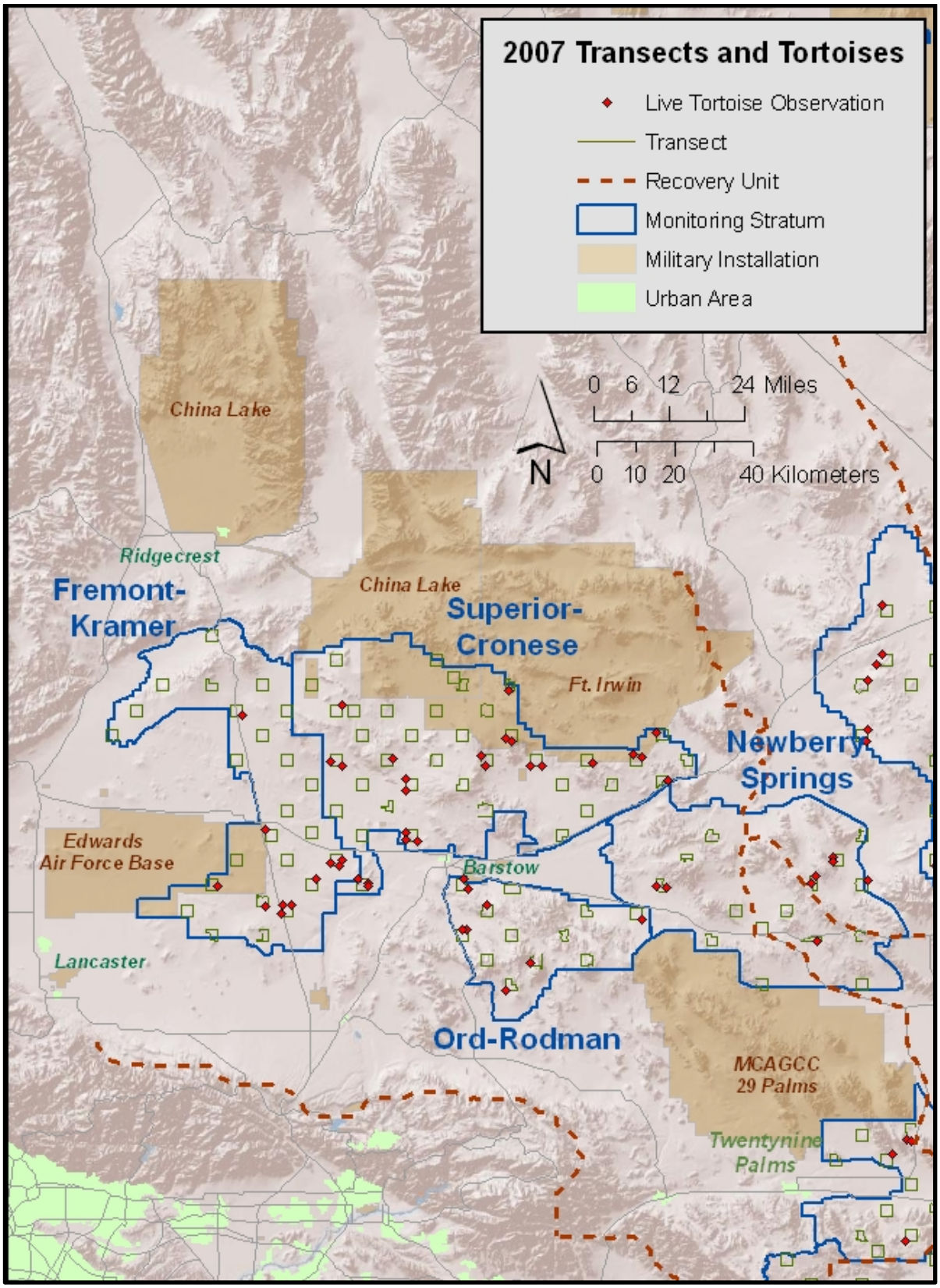


Figure 8. Distribution of distance sampling transects and live tortoise observations in the Fremont-Kramer, Superior-Cronese, Ord-Rodman, and Newberry Springs monitoring strata

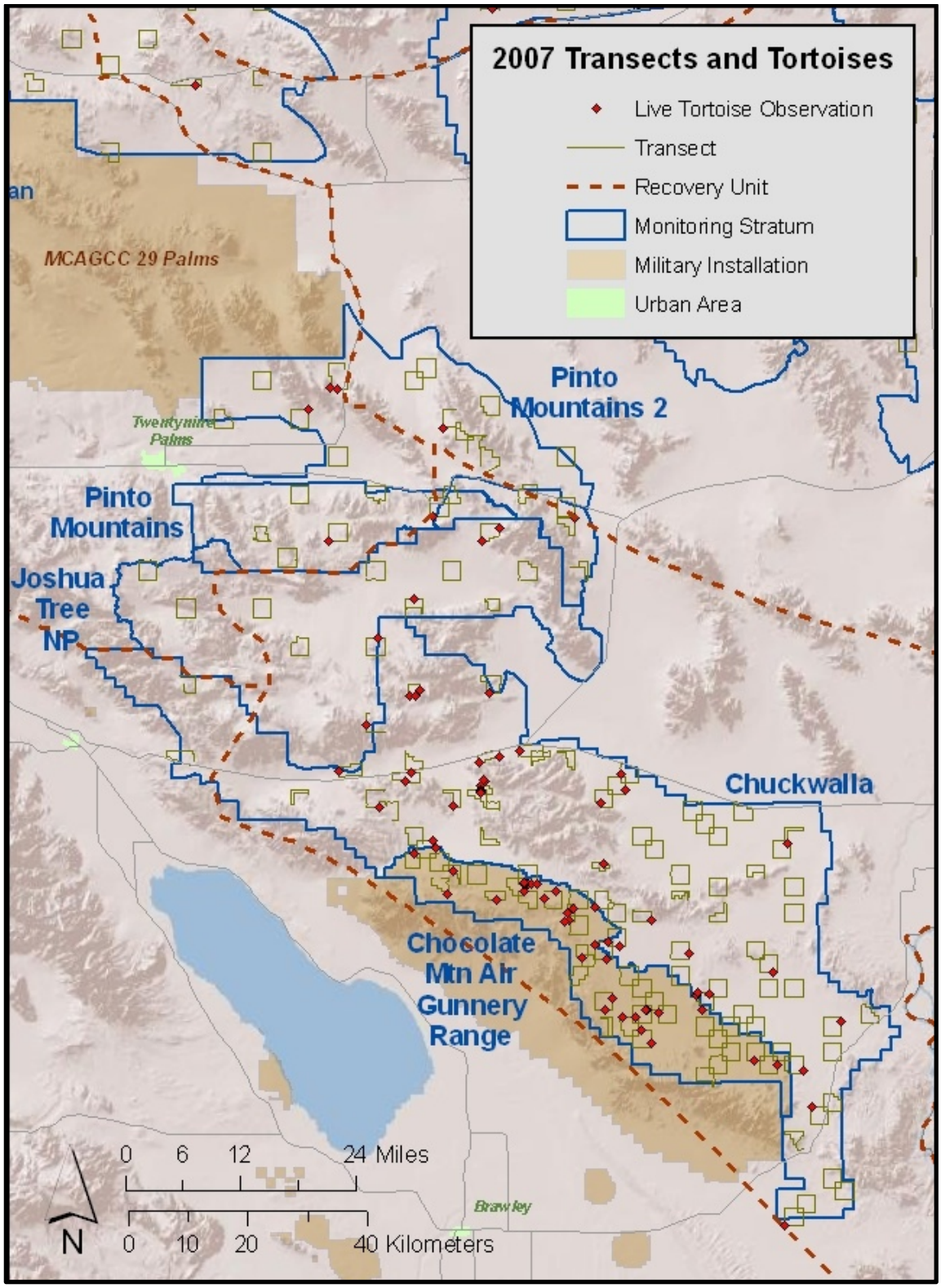


Figure 9. Distribution of distance sampling transects and live tortoise observations in the Pinto Mountains, Pinto Mountains 2, Joshua Tree National Park, Chuckwalla, and Chocolate Mountain AGR monitoring strata.

In 2007, crews were instructed to keep the transects centered in the assigned location, but to reflect as needed around obstacles. The expectation was that most of the rugged terrain would be sampled this way, and the transect locations would be representative, not purposefully in better areas for encountering tortoises. However, accommodation of rugged terrain resulted in modification of a high percentage of assigned transects (Table 6; average 32%, minimum 0%, maximum 60%), indicating that a more formal approach will be needed. Crews also applied variable interpretations of the guidelines for when and how to reflect transects. Although coverage in all strata was more even than in 2004 and 2005, when entire strata were also included in the sampling frame, these transects still oversample low-relief areas.

Table 6. Number and type of transects in each stratum.

Stratum	Assigned	Assigned and alternate transects completed*	Assigned, completed 12k square	Assigned, completed by reflecting around non-terrain obstacle	Assigned, completed by moving around terrain obstacle	Walkable assigned transects that were not walked*
AG	37	35	17	3	9	3
CK	68	65	23	6	24	0
BD	40	53	5	0	30	0
CS	99	88	28	2	44	15
GB	43	37	5	0	22	2
MM	93	62	17	6	31	11
PI	46	46	14	2	23	2
FE	15	15	10	1	0	4
IV	15	15	8	1	3	3
CM	15	15	12	0	0	1
FK	25	25	16	2	2	4
OR	12	12	3	4	3	0
SC	38	38	23	4	3	3
NS	15	15	2	2	7	0
JT	11	12	5	0	4	1
PT	12	11	4	0	4	0
PT2	13	13	6	0	5	0
Total	597	557				
Total in long-term strata	569	529				

*Assigned transects that were not walked were generally replaced by alternates.

Tortoise encounter rates and detection functions

Based on detection function behavior, all observations out to 12m (*w*) from the transect center line were used. Detection curves were estimated separately for each of the monitoring field teams (GBI and Kiva). For GBI (n=60), a uniform curve with simple cosine adjustment was selected; for Kiva (n=132), a uniform curve with second-order cosine adjustment was selected. Figures 10 and 11 are histograms of the observed number of tortoises seen at increasing distance from the transect centerline. These observations were used to model detection curves, overlaid in the same figures. The area below these curves is the proportion of tortoises that were detected out to 12m from the line, P_a. Based on these curves, GBI detected 61% of the visible tortoises within 12m of the centerline. The corresponding estimate of P_a for strata surveyed by Kiva was 0.49. Coincidently, estimates for both teams had the same CV(P_a)=0.086. No attempt was made to create detection functions for individual strata, where there were insufficient tortoise observations to develop detection histograms.

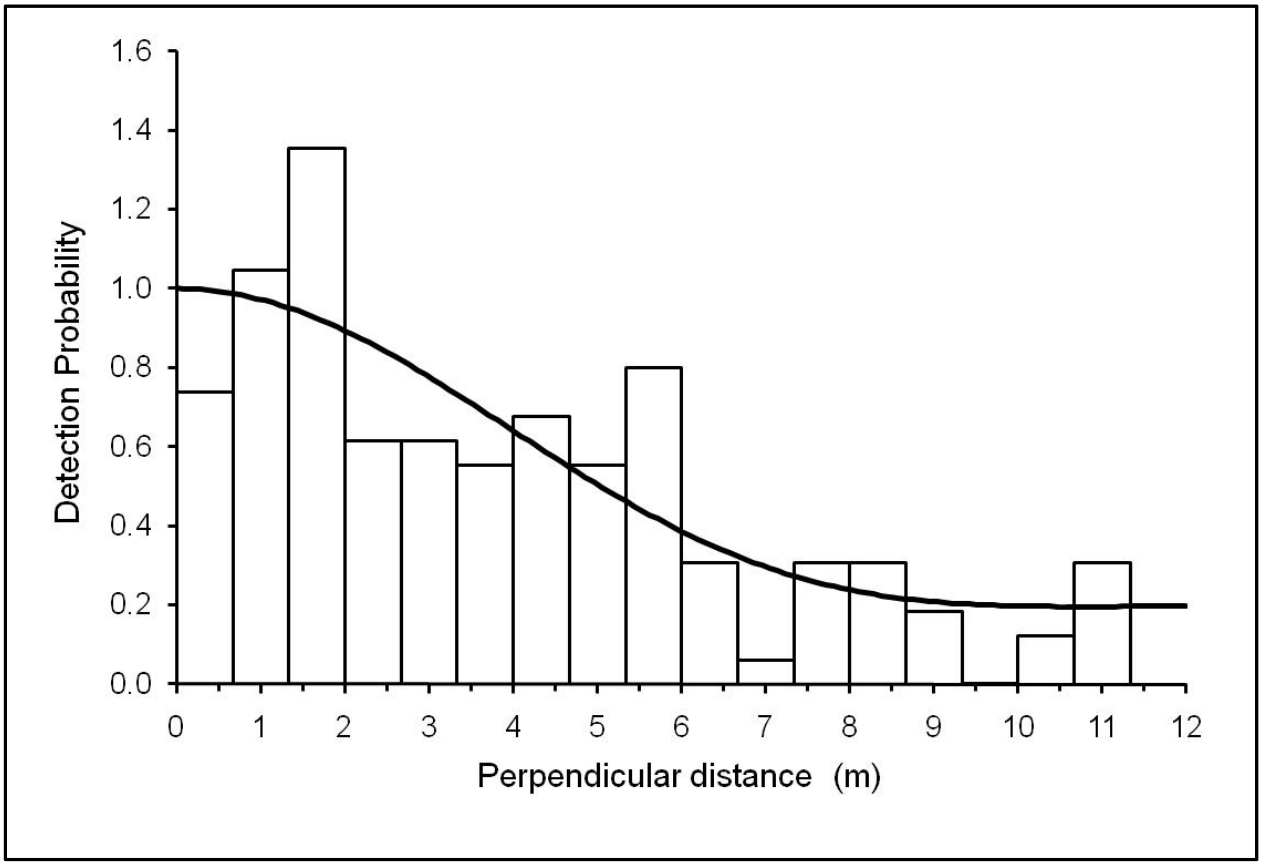


Figure 10. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by Kiva. Observations were truncated at 12m.

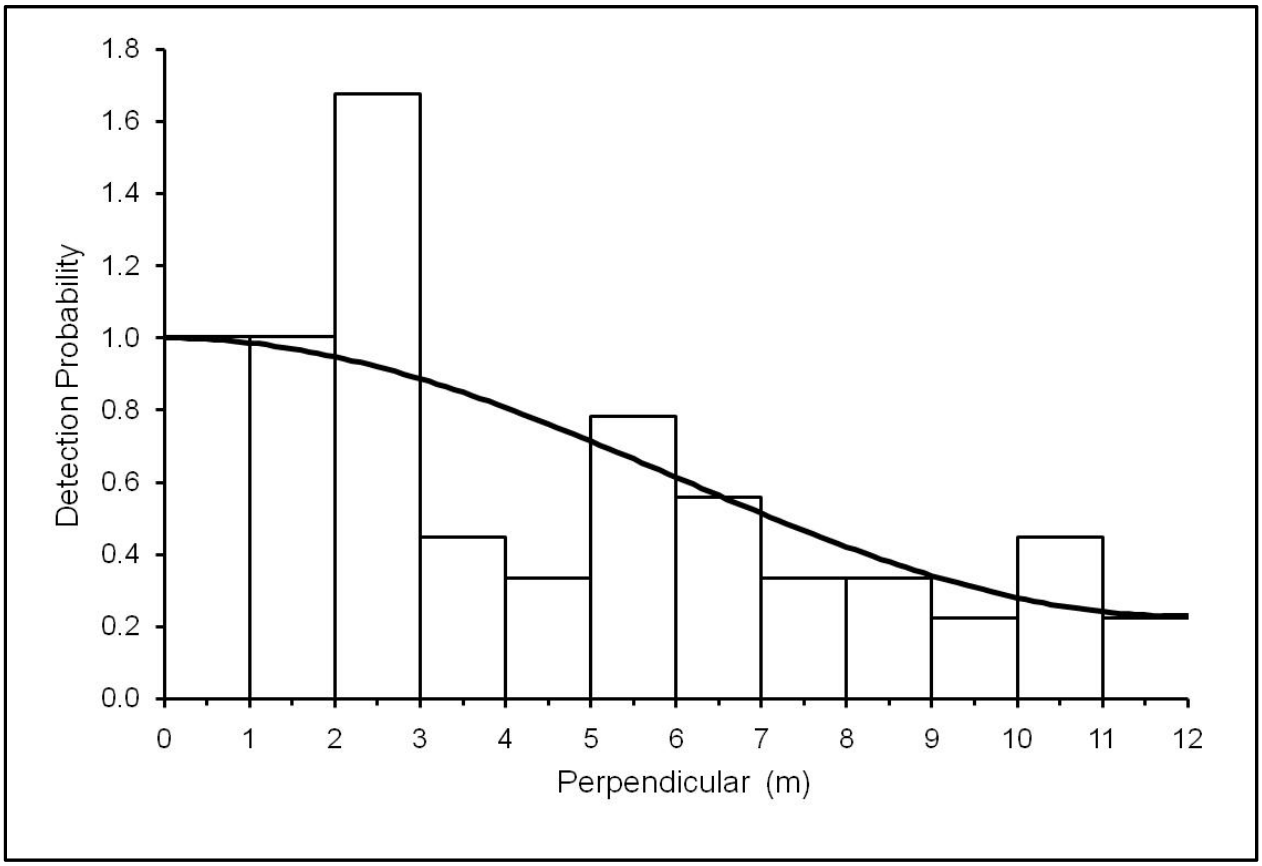


Figure 11. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by GBI. Observations were truncated at 12m.

Proportion of tortoises that are available for detection by line distance sampling, G_0

In general, telemetry sites and associated transects were completed sequentially, from south to north. This pattern corresponds to the expected timing of tortoise activity; activity should peak first in the south, later in the north. To match the scheduling of military operations on Chocolate Mountain Air Gunnery Range in Chuckwalla, the southern-most monitoring stratum, planning before the field season included a later start date for transects in the Chuckwalla stratum.

After the start of the field season, field crews changed their scheduling to 1) walk only the transects in the Pinto Mountains, Pinto Mountains 2, and Joshua Tree strata while tracking activity at the MCAGCC telemetry site, and 2) start walking transects in the Beaver Dam Slope stratum 20 days after initiating transects in other strata associated with the Coyote Springs telemetry site. These changes were addressed in the analysis by adding two more G_0 estimates to match the unique dates when Pinto Mountains, Pinto Mountains 2, Joshua Tree, and Beaver Dam Slope strata were walked. Dates, total days monitored, and G_0 estimates are given in Table 7.

Table 7. Availability of tortoises (G_0) during the period in 2007 when transects were walked in each group of neighboring strata.

G_0 sites	Strata	Dates	Days	G_0 (Std Error)
Piute, Chemehuevi, Ivanpah	Piute, Chemehuevi, Ivanpah, Fenner	1 – 9 April	9	0.79 (0.18)
MCAGCC	Joshua Tree, Pinto Mtns	6 – 11 April	6	0.97 (0.05)
Superior-Cronese, Ord-Rodman	Superior-Cronese, Ord-Rodman, Fremont-Kramer, Newberry Springs	13 – 26 April	14	0.80 (0.22)
Chuckwalla	Chuckwalla	28 April – 15 May	18	0.87 (0.06)
Coyote Springs	Coyote Springs, Mormon Mesa, Gold Butte	10 April – 30 May	51	0.79 (0.14)
Coyote Springs	Beaver Dam Slope	9 – 30 May	20	0.77 (0.17)

Proportion of available tortoises detected on the transect centerline, *g(0)*

Because they are cryptic, even tortoises that are visible (not covered by dense vegetation or out of sight in a burrow) may not be detected. For 31 detections of tortoises within 1m of the transect centerline, 24 were found by the observer in the lead position and 7 by the follower, so that the probability of detection by single observer, $p = 0.708$, and the proportion detected using the dual observer method, $g(0) = 0.915$ (SE = 0.13). However, Fig. 12 shows that $g(0)$ was converging on 1.0, indicating the assumption of perfect detection on the center line was met. No adjustment was made to the final density estimate. Because this assumption was not evaluated in USFWS (2006), Fig. 13 plots $g(0)$ estimates for the three monitoring years since 2004, when the protocol was changed to use dual observers instead of the earlier 3-pass method to detect every tortoise on the transect. The curves support the premise that complete detection on the transect line was achieved for all years in which the dual-observer method was used. Note, however, that in 2005 and 2007, at 1m from the line the follower reported a higher proportion of detections than they did at either 0.5 or 1.5m from the line, resulting in a dip in the curve. The basis for this pattern is unclear.

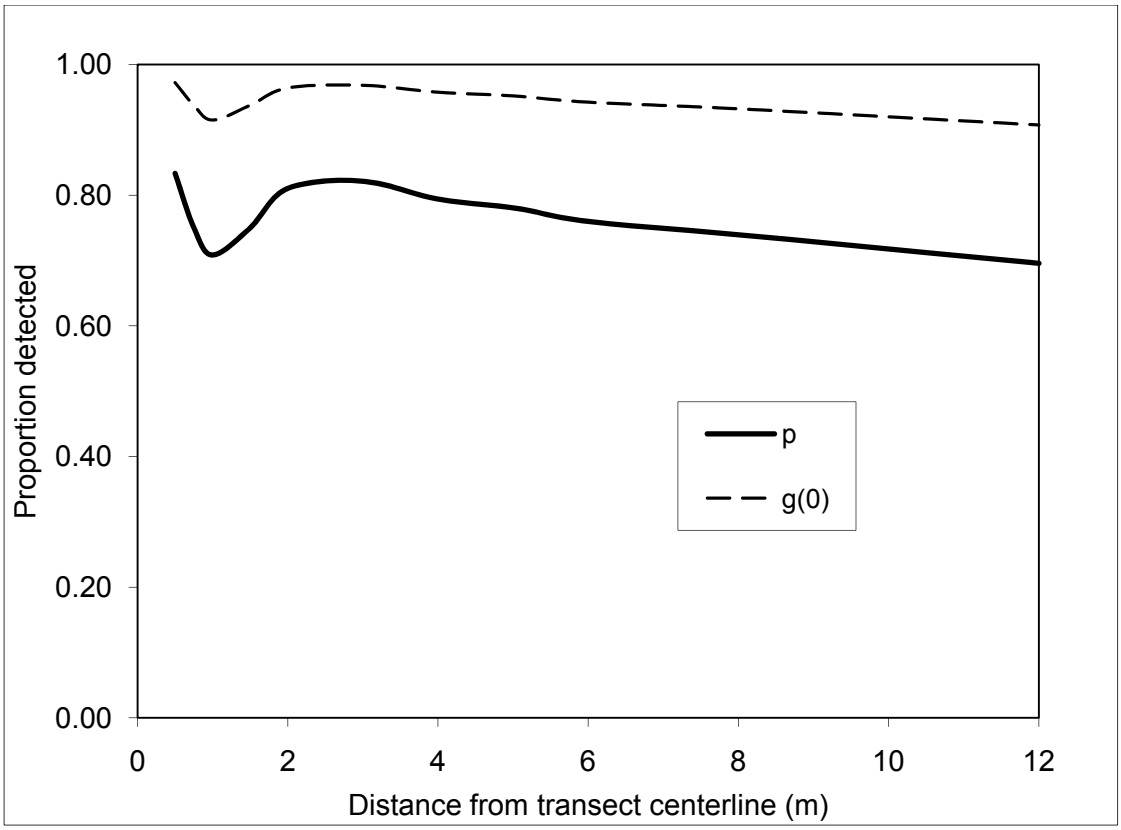


Figure 12. Behavior of detection on the line by the leader (*p*) and by the team (*g(0)*) based on all observations out to a given distance from the centerline in 2007. Note convergence of *g(0)* on 1.0 at the transect line (at distance=0).

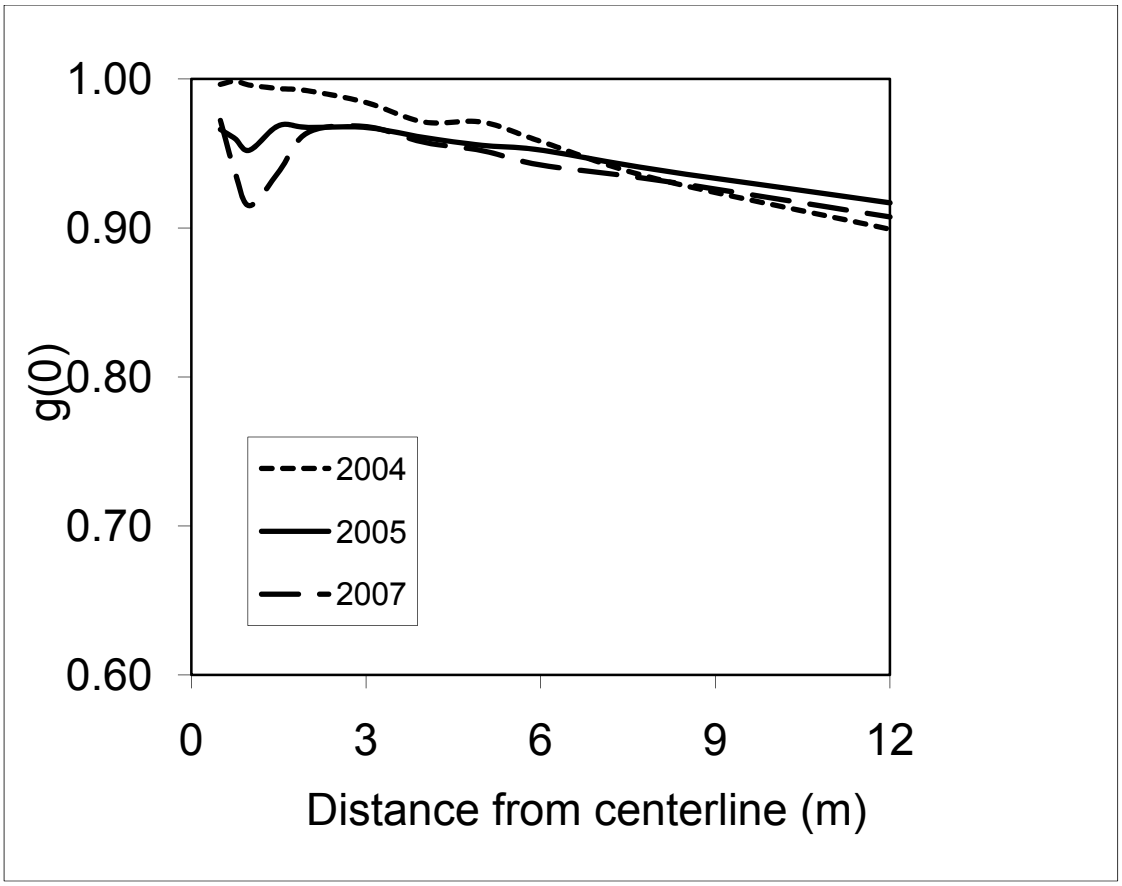


Figure 13. Estimates of *g(0)* based on smaller and smaller intervals of data around the transect centerline. The curves approach *g(0)* = 1 as the interval gets smaller. Curves are plotted for the 3 years when the dual-observer method was used.

Estimates of tortoise density

Density estimates were generated in DISTANCE separately for each monitoring stratum (Table 8). Stratum estimates were weighted by stratum area to arrive at average density in the monitored area of each recovery unit. Although encounter rates were estimated separately for each stratum, and have independent variances, the detection function and G_0 were estimated jointly (pooling data from multiple strata), so these variances are not independent (Figure 3 illustrated how estimates were pooled for 2007).

Recovery-unit-level density estimates are provided in Table 9. The final column indicates percent change from the updated density estimates for 2005 (Appendix D). In all recovery units, reported density is lower than in 2005. This might reflect true changes in population size, or might reflect the annual increases in the area of the sampling frame in each monitoring stratum; sampled areas have not been comparable from one year to the next. The only way to report comparable density or abundance statistics for years since 2001 will be to use model-based statistics, attempting to estimate density for unsampled areas (which are expected to have lower tortoise densities) based on sampled areas with similar characteristics (for instance,

Table 8. Recovery unit and stratum-level encounters and densities in 2007 for tortoises with MCL ≥ 180mm

Recovery Unit	Sampling Area		Area (km^2)	Number of Transects	Total Transect Length (km)	Sampling Dates Begin	Sampling Dates End	Field Observers	*n* (tortoises observed)	CV(*n*)	Density (/km)	CV(Density)
Northeastern Mojave			**4917**	**240**	**2316.1**	**10-Apr**	**30-May**		**46**		**1.7**	**25.0**
	Beaver Dam Slope	BD	828	53	478.0	9-May	30-May	GBI	6	46.8	1.2	53.2
	Coyote Springs	CS	1144	88	917.9	10-Apr	25-May	GBI	14	27.9	1.4	35.1
	Gold Butte-Pakoon	GB	1977	37	299.7	17-Apr	29-May	GBI	4	43.3	1.2	48.2
	Mormon Mesa	MM	968	62	620.5	10-Apr	25-May	GBI	22	22.8	3.3	31.2
Eastern Mojave			**6681**	**76**	**803.9**	**1-Apr**	**9-Apr**		**40**		**5.8**	**25.0**
	Fenner	FE	1862	15	178.2	1-Apr	6-Apr	Kiva	10	29.0	6.6	39.2
	Ivanpah	IV	2567	15	180.1	1-Apr	6-Apr	Kiva	10	23.9	6.5	35.6
	Piute-Eldorado	PI	2252	46	445.6	2-Apr	9-Apr	GBI	20	24.6	4.2	36.1
Eastern Colorado			**4263**	**100**	**1151.7**	**28-Apr**	**15-May**		**59**		**5.0**	**22.6**
	Chocolate Mtn AGR	AG	755	35	404.3	1-May	11-May	Kiva	27	21.2	7.1	25.3
	Chuckwalla	CK	3509	65	747.4	28-Apr	15-May	Kiva	32	25.4	4.5	29.0
Northern Colorado			**4038**	**15**	**180.0**	**1-Apr**	**6-Apr**		**7**		**4.6**	**43.4**
	Chemehuevi	CM	4038	15	180.0	1-Apr	6-Apr	Kiva	7	35.4	4.6	43.4
Western Mojave			**9298**	**97**	**1150.6**	**6-Apr**	**26-Apr**		**49**		**4.7**	**30.8**
	Fremont-Kramer	FK	2463	25	299.9	13-Apr	26-Apr	Kiva	7	38.7	2.7	49.3
	Joshua Tree NP	JT	1655	12	134.9	7-Apr	10-Apr	Kiva	4	58.8	2.8	60.2
	Newberry Springs*	NS	2682	15	172.2	16-Apr	22-Apr	Kiva	5	54.5	3.4	62.4
	Ord-Rodman	OR	1124	12	140.9	13-Apr	25-Apr	Kiva	10	35.3	8.2	46.7
	Pinto Mountains	PT	608	10	119.4	6-Apr	11-Apr	Kiva	3	50.7	2.4	52.4
	Pinto Mountains 2*	PT2	1113	14	161.4	6-Apr	11-Apr	Kiva	4	58.1	2.4	59.5
	Superior-Cronese	SC	3447	38	455.5	13-Apr	25-Apr	Kiva	25	25.1	6.3	39.6

* These strata are not part of long-term monitoring and were not included in recovery-unit summary rows.

elevation and/or vegetation type). This will be a more productive exercise once the draft Recovery Plan (USFWS, 2008) is finalized and recovery units with associated tortoise conservation areas have been confirmed.

The Northern Colorado Recovery Unit was under-sampled in 2007, reflected in the low precision (high CV) in Table 9. The low precision means that high between-year fluctuations in estimates are to be expected. Finally, the apparent population decrease in the Upper Virgin River Recovery Unit was described in McLuckie et al. (2008) as continuation of a pattern since 2003 of increased mortality from wildfires, disease, drought, and habitat degradation.

Table 9. Estimated density of desert tortoises in monitored areas of each recovery unit in the Mojave Desert in 2007.

Recovery Unit	Monitored area (km^2)	Transects	Tortoises detected	Density ($/km^2$)	SE(Density)	%CV (Density)	% change from 2005[b]
Eastern Colorado	4263	100	59	5.0	1.13	22.63	-37
Eastern Mojave	6681	76	40	5.8	1.44	24.98	-20
Northeastern Mojave	4089	240	46	1.7	0.42	25.03	-9
Northern Colorado	4038	15	7	4.6	1.98	43.36	-58
Western Mojave	9298	97	49	4.7	1.45	30.77	-23
Upper Virgin River[a]	114	157	92	14.9	2.04	13.70	-32

[a] Data for Upper Virgin River taken from McLuckie et al. 2008.

[b] A decrease in reported tortoise densities was expected in 2007 as a simple result of placing transects throughout monitoring areas. In past years, including 2005, field crews completed surveys in areas of lower topography and in areas generally expected to have more tortoises. As indicated in the text, the shifting sampling frame will have to be addressed before interpreting any apparent "trends."

Appendix D provides density estimates for each recovery unit in the years 2001 through 2005. In addition to the original estimates (USFWS, 2006), the table reports densities using the updated analysis approaches initiated in 2007. It should be expected that the recalculated density estimates would be less precise once the incorrect calculation of G_0 was addressed. In addition, there is considerable variability (in the original and recalculated estimates) from year to year in the same recovery unit. For instance, in the Western Mojave the [revised] estimate is 4.4 tortoises/km^2 in 2004, up 30% to 6.1 in 2005, then down 25% to 4.7 tortoises/km^2 in 2007. This does not reflect realistic changes in population size in such a large area over one-year periods, but it is a consequence of the relatively imprecise annual estimates. When the annual estimates are imprecise, it should not be expected that there will be a close match from one year to the next. Over a period of many years, however, any underlying trend in the number of tortoises should be obvious through this "background noise."

Debriefing to identify strengths and weaknesses in preparation for future years

In previous years, planning did not include participation by field crews. This was also the case for 2007. However, it became apparent during the field season that this input would be necessary

to address problems in training and data systems. My field visits with both of the groups providing field crews made it clear there were various ways that protocol and field season planning could be improved. As a result, two post-season debriefing meetings were held (one each for data management and field season preparation) to include representatives from all groups responsible for creating as well as using products. Field crew members were surveyed prior to the end of the field season to identify areas to target for improvement; although most crew members had finished their contracts and left before the debriefing meeting, survey results were provided to meeting participants, and some crew representatives were present. The meetings also included participants with data management (collection database development, QAQC I and II) and training responsibilities.

Study design

Because G_0 contributes the largest variance to density estimates, for 2008, it will be important to make more explicit connections between G_0 site data and information collected on transects. This involves more data collection to characterize visibility using transect protocols and visibility after tortoises are located using radiotelemetry. This additional data should clarify how detection in burrows and on the surface may differ based on the two ways to describe detectability (visual detection on transects compared to detection that also includes radio receivers).

Fewer alternate transects should be walked, with more emphasis on walking assigned transects. In 2007, alternate transects were used for some transects because the planned transects could not be accessed; this issue can often be overcome with funding for earlier planning. Other transects were walked, but the full 12km was not completed. Rules for alternative navigation of transects in rugged terrain were not written and distributed for 2007 until the field season had started, after requested by field crews. In future years, these guidelines will be part of start-up contract meetings and will be a subject of specialized training.

Training

Training for each year of the monitoring project, including 2007, has been developed around refining the search procedures of crews in California that were already proficient at finding desert tortoises using other techniques, and for training inexperienced student interns for monitoring the rest of the range. These inexperienced crews had been trained separately to acclimate to the desert and handle tortoises. The official training week itself served as the time when any protocol changes were introduced and when crews were tested for ability to detect fabricated tortoise models to give the correct detection curve.

As a result of the 2007 field season debriefing, a goal for 2008 was to use the training program to further standardize and consolidate the range-wide monitoring program. A specific objective was to develop a training program that frees the project from the constraints of using only experienced crews in California and relying on student crews in Nevada. This would also strengthen the monitoring program by severing its reliance on contracted crews with previous

experience. The training program should be usable by inexperienced crew members from California as well, and experienced crew members from all contracted field teams should be involved in training on sampling techniques.

Standardization would also require a more comprehensive training program, with formal goals and objectives, and a monitoring handbook that could serve as reference for crews during the field season. At the debriefing meetings and subsequent communications, the following modules were identified. They were put into development by UNR for the 2008 field season (Table 10).

Table 10. Training modules to have objectives, standards, and metrics developed for 2008

Training module	Offered in 2007?*
Tortoise handling	Informally
Line distance sampling theory	Yes
Navigation – GPS and compass	Informally
Navigation on public lands	No
Implementation of line distance sampling techniques	Informally
RDA/Bluetooth GPS	Yes
Radio telemetry	Informally
Field contractor QAQC	Yes
Data collection	Informally

*"Informally" refers to training without written material, expressed objectives for training, and availability to all inexperienced crews.
"Yes" implies some written material, consequent opportunity for standardization across crews, and availability to inexperienced crews.

Field data collection

- Future field seasons should reflect more similar responsibilities between all field teams for providing their own logistical and material support. Some electronic equipment will be provided by the USFWS to all field crews, and equipment that does not require standardization will be the responsibility of the contracted teams. This will represent a change in the eastern part of the range in particular, where monitoring crews worked directly under UNR, which also had a strong leadership role in the range-wide effort.
- Database transfer procedures have been changed so that field crews can stay overnight in the field without data backup, and a laptop computer will travel in the field for collecting data from separate RDAs. This will increase logistical options for completing transects in remote areas.
- Transects that were not completed due to rugged terrain will have improved completion records once protocols for rugged terrain are in place.
- The same set of transects will form the core of sampling for 2008 as for 2007. Using information collected on transects in 2007, planning for transect access could start in the fall before the next spring field season, which will improve the transect completion record (see above *Study Design* improvements). It is clear that some transects have

accessibility issues, which can be planned for through coordination with local land managers. The USFWS has requested/invited increased land management agency representation at monitoring coordination meetings. One benefit will be updating maps and access information for future field seasons.

Data management

- A team was created at the debriefing meeting on 6 June 2007. This team began active coordination to provide materials for improved database design, for more extensive and targeted error-checking scripts, and to test the prototype collection database for 2008.
- Early development of the database was identified as an important part of training development. This development includes drafting a data dictionary that clarifies fields in the data forms and identifies those that require further instruction during training in order to reduce errors.
- To provide clarity and improve coordination between contractors involved in different stages of data handling, a data management plan will be in place in January before each field season. This is sufficient for all parties to be prepared for their responsibilities in the three stages of quality control.

Coordination, tasks and timelines

- Continue the open evaluation procedure by inviting field crews to debriefing meetings.
- Use agreements, planning meetings, and training to standardize monitoring range-wide.
- Restructure coordination meetings away from advisory functions to reporting and collaboration functions
- Move new functions to the oversight of the USFWS. In 2008 and subsequent years, USFWS will have a larger role in training, weekly field season oversight, and in data management.

When planning for the 2007 field season started in 2006, a proposed annual schedule had been developed based on the collective experience of UNR, MDEP, and Topoworks cooperators. This schedule was designed around data quality control needs. It served as the starting point for 2007 planning, although funding availability was one source of deviation from the schedule. After the debriefing meetings, at which the assembled groups developed timelines for completion of 2008 planning tasks, an updated schedule was developed.

Table 11 lists the tasks, the timeline proposed in 2006 for the 2007 field season, the timeline implemented in 2007, and the timeline recommended for 2008. Some times have shifted considerably, and unanticipated tasks have been added, primarily as a result of input from field monitors to this process.

Table 11. Planned and actual timelines for desert tortoise monitoring in 2007 and planned completion dates for the 2008 field season.

Activity	Product	2007 Planned Date*	2007 Actual Date*	2008 Planned Date*
Previous field season debriefings	Improvement activities and timelines	22-Oct	15-Jun	30-Jun
Coordination meeting	Updated timelines	15-Nov		20-Aug
Identify changes in data needs	Final database fields		1-Apr	1-Sep
Identify number of transects required	Number of transects required for each stratum	20-Oct	1-Nov	20-Oct
Develop collection database	Digital data form	15-Dec	25-Mar	1-Dec
Generate survey strata and transects	GIS shapefiles of monitoring strata and transect start points	15-Nov	15-Mar	15-Dec
Outline data processing steps	Final 2008 QA/QC Plan	28-Feb	25-Mar	1-Jan
Develop training program	Final Training Handbook	1-Apr	25-Mar	1-Jan
Develop and present budgets	Agency budget commitments	2-Jan	2-Jan	2-Jan
Develop collection QA/QC database	Digital database	15-Jan	25-Mar	15-Jan
Access coordination	Updated access information			15-Jan
Coordination meeting	Final coordination meeting	15-Feb	15-Dec	15-Jan
Develop and award contracts	Field crew contracts in place	30-Jan	1-Mar	30-Jan
Submit research permit requests	Federal and state permits	1-Nov	15-Feb	31-Jan
Develop maps for field crews	Paper maps for each stratum	15-Feb	15-Apr	1-Feb
Develop and coordinate	Training course preparations	15-Mar		1-Feb
Plan transect access	Transect completion strategy	28-Feb		28-Feb
Test contractor database	Final database & data forms	15-Feb	1-Apr	15-Mar
List of Authorized Individuals	Submit crew qualifications to permitting agencies	1-Feb	15-Mar	15-Mar
Conduct training	Trained field crew	30-Mar	30-Mar	30-Mar
Training reporting	Training report			30-Apr
Conduct field surveys	Contractor database	15-Jul	27-Jun	15-Jun
Field season reporting	Debriefing report			31-Jul
QA/QC 2	2nd level database	Continually	30-Aug	30-Aug
Quality control report	QAQC performance report			31-Oct
Results reporting	Range-wide density report		31-Dec	30-Nov
Annual reporting	Range-wide summary report		31-Dec	31-Dec

*Dates are sequential based on 2008 planned dates and start the year before field work is done.

DISCUSSION

Sampling representatively in all monitoring strata

In 2007, transects were placed systematically in monitoring strata; the placement scheme itself had a random origin so that transects were located at random with respect to tortoises. The goal of systematic placement is used to provide better coverage of sampled areas, and the set of potential transect locations will be used to sample from in future years as well. Because transects can be rewalked in the future, it is meaningful to collect information describing access and completion of each transect so that this information is available when planning to walk this transect location in future years.

Better planning opportunities should improve representative sampling in each monitoring stratum. Another change implemented to improve coverage was redevelopment of the set of rules for changing standard transect protocols when confronted with particular obstacles (Appendix A). Site visits with crews and visual (GIS) inspection of how these rules were applied on specific transects revealed that these guidelines were not always applied consistently. During end-of-season debriefings, crews reiterated that the rules were difficult to apply. A much-simplified, intensively instructed protocol for non-standard situations was developed for 2008.

These new rules are part of increasing efforts since 2004 to cover all areas within sampling strata. Even if tortoise numbers remain constant, it is expected that estimated tortoise densities will be lower if many of the areas added to the sampling frame contain lower densities of tortoises than the core areas sampled among all years. Estimates of density for 2007 are lower than previous estimates from 2005 (Table 9). This change coincides with efforts described above to sample from all of the areas managed for desert tortoises; the new areas of interest were excluded in the past as potentially low suitability to desert tortoises or logistical difficulties that may also correspond to lower tortoise densities.

How are density estimates to be compared between years? Unless there has been representative sampling, “design-based” density estimates are not possible, so they can only be compared if it is possible to generate “model-based” density estimates. This involves using model-based statistics to estimate density for unsampled areas based on sampled areas with similar characteristics. Transects might be characterized by whether they are in low- or high-relief areas, as a simple example. Even if high-relief areas were relatively under-sampled, a modeling approach could estimate the expected density in these areas based on the samples we do have. Based on the experience and transect descriptions generated by field crews in 2007, a design-based sampling approach was planned for 2008.

Estimation and use of G_0 to adjust density calculations

The previous report on the range-wide monitoring program (USFWS, 2006) drew attention and questions about reliance on a set of sites where radio-equipped tortoises are monitored to adjust abundance estimates for the proportion of tortoises that are not visually detectable. Criticism has focused on the software limitation that was used to explain why only one activity estimate could be applied to all transects across the range (USFWS, 2006). On the one hand, this has led to some questions about the value of maintaining so many focal sites (8 in 2007) when only one estimate is used, and on the other hand has led to criticism for allowing software to limit the ability to analyze data appropriately. Following assessment of the overall recovery effort (Tracy et al., 2004) and then the first five years of the range-wide desert tortoise monitoring program (USFWS, 2006), a consistent theme was the need to develop stand-alone analysis capability so that better and more customized density estimates could be developed.

Questions about the maintenance of multiple telemetry sites led researchers and agencies to ask whether a more cost-effective way could be found to adjust density estimates. Monitoring data from this program since 2001 indicates the enticing possibility that a simple model of tortoise "availability for detection" could be built, because G_0 estimates are usually very close to one another for different areas across the range (0.7-0.9 is typical). Recently, Inman (2008) began to address whether tortoise activity levels could be modeled using relatively inexpensive environmental measurements to bypass more expensive tortoise behavior monitoring. He collected relevant data to model individual tortoise behavior, and applied this to predicting population above-ground behavior over full 24-hour periods from mid-April to the end of June. This period includes the normal spring activity period (through mid- to late May), as well as a month (June) when above-ground activity is considered limited. Inman (2008) does not suggest that these modeling approaches will be successful for the range-wide monitoring program. Because he was describing individual-based variation in behavior, his models were mechanistic and more complex than the simpler phenomenological question, more pertinent to the issue of range-wide monitoring: How many are above ground at any one time? Inman (2008) does criticize the exclusive use of Program DISTANCE to complete distance analyses, and we are also in agreement on that point.

The design of the range-wide monitoring program limits G_0 to an acceptable range of variability. Restricting monitoring to 1 April to 30 May and constraining the time of day when sampling can occur (starting no earlier than 7am until 1 May, no later than sunrise thereafter), has the effect of incorporating qualitative models of tortoise activity to optimize the number of tortoises that are above-ground. However, this qualitative model is not sufficient to estimate the variance of tortoise activity or to forecast how the estimate itself will vary (2002 was an anomalous year, for instance), so for the immediate future, the monitoring program will continue to rely on focal tortoises in telemetry sites for local activity estimates. It remains to be seen whether modeling might be more successful for describing tortoise activity within the constraints of month (April-May) and time of day (sunrise to noon or mid-afternoon) when monitoring is conducted. Also, it

is not always possible to monitor during the best period for a particular site. Due to annual military operations scheduled on Chocolate Mountain Air Gunnery Range, transects cannot be completed in early April, when the highest activity levels are expected to occur, close to or exceeding 0.80. All of these reasons indicate the value of maintaining regional sites to estimate tortoise detectability.

The second critique of the monitoring program's use of G_0 is that analysis should not be constrained by available software to use only one estimate for G_0. Starting in 2007, I used the most powerful features of Program DISTANCE to reasonably constrain and estimate detection functions, to estimate stratum-specific encounter rates, and to estimate variances for both. These estimates (for encounter rate and detection probability) were subsequently incorporated with one another and with regional G_0 estimates outside of DISTANCE in a final customized analysis that produced density estimates (and confidence intervals) for individual strata as well as recovery units. The regional G_0 estimates are also much more precise than a single, range-wide estimate would be, so maintenance of telemetry sites across the range provides more accurate and more precise density estimates.

Improving ability to detect trends in desert tortoise abundance

The primary goal of the monitoring program is to provide population estimates that are relevant to the recovery plan criteria (USFWS, 1994). The priority for the 2007 field season was therefore to improve ability to detect trends in desert tortoise abundance at the recovery unit level.

Impact of developing regional G_0 estimates

The changes described in the previous section, allowing use of more than one estimate of G_0, were an important step in developing precise density estimates. Analysis before the field season (Appendix B) indicated that: 1) a large source of variance to density estimates has been the estimation of G_0, and 2) much of the day-to-day variance in G_0 is due to monitoring over large spatial scales (where factors affecting tortoise activity may vary considerably) and over relatively large temporal scales (entire spring activity seasons) that describe activity over a period when the phenology of annual food plants changes considerably and when thermal regimes change markedly.

For 2007, the study design was changed to minimize the variance of G_0. Each telemetry site and neighboring transect strata were completed in sequence so that they could be completed as quickly as possible and so that only a limited spatial area was described. In some areas of the range in 2001 to 2005, a similar grouping approach had been used, completing local transects and monitoring telemetry sites in a short period of time. However, this approach was not used consistently, and the previous method of analyzing data could only accommodate one G_0 estimate per year. Table 12 reports G_0 estimates and coefficients of variation (a measure of precision) at sites that were monitored in 2005 and 2007. One site, Ivanpah, was monitored for the same number of days in both years. The CV both years and number of days were all among

the lowest reported. At four of the remaining six sites, precision was higher (CV lower) when the site was monitored for a shorter time. This is not a strong pattern, but it is promising as one approach in the effort to increase the precision of the density estimates.

One of the sites that did not match the pattern was Ord-Rodman, where variability over 13 days in 2007 was high, and tortoise availability averaged only 64%. Because availability at this site was combined with that from Superior Cronese, where availability was uniformly high (94%), the spatial variability between the two sites was also high. This level of spatial variability was not as great in the Chemehuevi, Piute, and Ivanpah group of G_0 sites, although activity at Chemehuevi was consistently lower than that at Piute and Ivanpah during the same nine days of observation. Average G_0 (and CVs) for groups of sites is given in Table 7.

Table 12. Comparison of estimated G_0 and percent CV(G_0) at telemetry sites monitored in 2005 and 2007.

	2005			2007		
Telemetry Site	G_0	% CV(G_0)	Days	G_0	% CV(G_0)	Days
Chuckwalla	0.74	20.5	39	0.87	6.9	17
Chemehuevi	0.65	26.6	40	0.62	19.1	5
Ivanpah	0.87	11.7	5	0.94	9.7	5
Piute-Mid	0.91	13.0	59	0.81	22.0	7
MCAGCC	0.90	12.2	21	0.97	4.8	5
Ord-Rodman	0.92	9.0	32	0.64	33.4	13
Superior Cronese	0.92	10.3	37	0.96	5.2	13

Consequences of insufficient transects

Appendix D highlights recalculated density estimates at the level of the recovery unit. In some cases, such as the Northeastern Mojave in 2002, a density was reported in USFWS (2006) and is reprinted in Appendix D, but due to the very small sample size, a new estimate was not included in this report. Although in general less sampling effort is needed to develop a reasonable estimate of encounter rate (tortoises detected per kilometer walked) than to model a detection curve or estimate the proportion of visible tortoises, only 3 live tortoises were encountered on transects in the entire Northeastern Mojave sampling effort in 2002. This is of course too few to develop a useful encounter rate estimate for an entire recovery unit. In fact, no tortoises were encountered on transects in 3 of the 4 associated monitoring strata, so it would also be inappropriate to extrapolate an estimate for the entire recovery unit based on limited observations from a single stratum. Whereas much of this report has focused on ways to enhance efforts and develop more precise estimates to detect trends, this example illustrates that attention should also be focused on the lower limits of effort that can produce useful data. There should be sufficient transects in each monitoring stratum each year to detect several live tortoises in each stratum. This is one

reason that over the years since 2001, the protocols have changed to allow more kilometers to be walked per day, increasing the number of tortoises encountered. However, the number of transects walked is limited by funding, which was only sufficient to complete 10 – 15 transects in 6 of the 9 long-term strata in the California portion of the range in 2007.

Reporting density estimates at other relevant spatial scales

Although the monitoring program is focused on density estimation for recovery units, it can also be compatible with reporting density estimates at smaller spatial scales that are relevant to recovery efforts and to land management agencies. The copyrighted software for distance analysis (Program DISTANCE, ver. 5.2), however, does not accommodate more than one level of stratification, so previous software-dependent analysis generated density estimates at only one level of analysis – the recovery unit. (This limitation is separate from the fact that only one estimate of G_0 can be used for each analysis.) By utilizing Program DISTANCE for the first analysis stages, then leaving the program for the final steps of the analysis, in 2007 I was able to provide separate density estimates for each monitoring stratum, as well as for one area smaller than a monitoring stratum (Chocolate Mountain Air Gunnery Range). Appendix C provides stratum level density estimates for all years of the monitoring program to date. This approach to analysis for the range-wide program, and revived attention to putting sufficient effort (transects) in each stratum, will allow for density estimates in each stratum each year.

LITERATURE CITED

Anderson, D.R., and K.P. Burnham. 1996. A monitoring program for the desert tortoise. Report to the Desert Tortoise Management Oversight Group.

Anderson, D.R., K.P. Burnham, B.C. Lubow, L. Thomas, P.S. Corn, P.A. Medica, and R.W. Marlow. 2001. Field trials of line transect methods applied to estimation of desert tortoise abundance. Journal of Wildlife Management 65:583-597.

Averill-Murray, R.C. 1999. Monitoring tortoise populations in the Sonoran Desert: a power analysis. Proceedings of the Desert Tortoise Council Symposium 1997-1998:1-9.

Averill-Murray, R.C., and A. Averill-Murray. 2005. Regional-scale estimation of density and habitat use of the desert tortoise (Gopherus agassizii) in Arizona. Journal of Herpetology 39:65–72.

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas. 2001. Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford Univ. Press, Oxford. 432 pp.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology 68:1364-1372.

Inman, R. D. 2008. How elusive behavior and climate influence the precision of density estimates of desert tortoise populations. M.S. Thesis. University of Nevada, Reno. 120pp.

Krzysik, A.J. 2002. A landscape sampling protocol for estimating distribution and density patterns of desert tortoises at multiple spatial scales. Chelonian Conservation and Biology 4(2):366-379.

Marques, T.A., L. Thomas, S.G. Fancy, and S. T. Buckland. 2007. Improving estimates of bird density using multiple-covariate distance sampling. The Auk 124(4) 1229-1243.

McLuckie, A.M., M.M. Reitz, and R.A. Fridell. 2008. Regional desert tortoise monitoring in the Red cliffs Desert Reserve, 2007. Salt Lake City: Utah Division of Wildlife Resources, Publication Number 08-19. 57pp.

SPSS for Windows, Rel. 16.0.2. 2008. Chicago: SPSS Inc.

Swann, D.E., R.C. Averill-Murray, and C.R. Schwalbe. 2002. Distance sampling for Sonoran desert tortoises. Journal of Wildlife Management 66:969–975.

U.S. Fish and Wildlife Service. 2006. Range-wide Monitoring of the Mojave Population of the Desert Tortoise: 2001-2005 Summary Report. Report by the Desert Tortoise Recovery Office, U.S. Fish and Wildlife Service, Reno, Nevada.

U.S. Fish and Wildlife Service. 2008. Draft revised recovery plan for the Mojave population of the desert tortoise (*Gopherus agassizii*). U.S. Fish and Wildlife Service, California and Nevada Region, Sacramento, California. 209 pp.

White, G.C., D.R. Anderson, K.P. Burnham, and D.L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. LA-87-87-NERP. Los Alamos National Laboratory, Los Alamos, NM. 235pp.

APPENDIX A. GUIDELINES FOR NON-STANDARD TRANSECTS

These guidelines were developed in the first week of April (after training) and provided to field crew leaders.

Below, some guidelines are laid out for planning transects. When possible, crews should have a plan for each transect before they arrive on site. However, that is not always possible, so the goals that should guide planning and on-site deviations from assigned transects are given first.

Goals of transect layout:

1. Transects sample areas defined by strata boundaries

    All terrains and habitats in the stratum are proportionally represented across the total kilometers walked in the stratum.

2. Transects are placed independent of tortoise locations

    Within strata, transects are placed without considering terrain, vegetation, or other potential predictors of tortoises.

3. Transects have been placed with optimal spacing between transects. This spacing would allow for additional transects to be added in years when there is sufficient funding.

    Moving transects away from their center point creates problems with transect spacing.

Guidelines (in order of priority) that arise from these goals:

1. Walk the assigned transect unless impossible in allotted time. (Goals 1, 2, 3)

2. Reflect transects.

    Any reflection should be mapped out before crews are on-site (Goal 2)

    Reflection should be designed to keep as many kilometers of the original transect in place as possible. (Goal 1; kilometers are important, not the start point or other corners *per se,* but see Goal 3 regarding moving all corners and the transect center point)

        In the past, reflection has been at right angles to the line of travel. East-west and north-south obstacles (for instance, many major roadways in the Mojave Desert) cannot be reflected from by moving at right angles. If crews are confident they can walk in a straight trajectory without following an easting or northing reading, please reflect at non-right-angles instead of "sliding" transects away from obstacles. If non-right-angle reflection is not possible, choose the side of the obstacle where most of the transect occurs. Flatten the transect into a 12-km

rectangle. For instance, if the transect is to be walked on the north side of a road that bisects it, the transect will be shorter in the north-south direction. Add this distance back in by extending the transect by the same number of waypoints to the west as you add to the east. (Goal 3)

3. Walk a shorter, square transect.
In some terrain, reflection may be constrained by ravines, excessive number of required reflections, etc. Instead, it is preferable to walk in a smaller square that requires less human judgment. The exact waypoints at which the square will be shortened can be determined while on the transect. If, after ~¼ of the allotted time, the crew decides they will not be able to complete the transect in the allotted time (for instance, they haven't completed one 3-km side), a right turn should be made to create the second leg of a smaller transect. The length of the first side sets the distance to walk the remaining 3 sides. In this way, the crews will also return to their start point. (Goals 1, 2)

Note that this option is also available if transit time to a transect means that a 12km transect cannot be walked without endangering the crew. If a crew begins hiking to a transect at first light, time to transect and feasibility of the transect could not necessarily be determined before starting out. After arriving at the transect, the crew can determine the total time they should spend on the transect before hiking out again and can resize the transect accordingly.

4. Interrupt the transect to navigate obstacles but allow most of the designated transect to be completed as planned. Some transects cross a ridge or have other relatively short, steep sections where LDS walking and searching techniques are probably not going to be implemented. When small obstacles occur on a transect, crews can use a short scramble (~20-30m) to get up or over something, look really hard before scrambling, turn around look really hard again. The lead scrambles up with the line, the follow stays at the bottom. After the line has been examined by both the lead and the follow, the follow scrambles up to meet the lead and the line is resumed as normal. The transect follows the regular assigned path.

However, if the obstacle requires more distance than this to navigate, and a really hard look will not cover the distance, the best option is to not collect data over this distance; the crews can "interrupt" the transect. Find a safe route around the obstacle and resume the transect at the point where it can once again be navigated. This will result in a shorter distance covered, but only a minimal deviation from the planned transect. (Goal 2)

Data form procedures: If a transect is interrupted as described here, there are important changes required to document the fact that data are not collected for part of the planned transect. In order to clearly implement this in the database the transect will be officially

ended at this point of interruption (i.e. end waypoint 99, end time, summary of observations, etc. are all recorded). After the obstacle is navigated, crews will begin a totally new transect. The number for this transect is based on the original transect number. If the original transect was 42, for instance, the transect number for the section after the obstacle would be 42.1. If another interruption is required, a new transect would be created and designated as 42.2.

Treating the walkable segments as separate transects is an important bookkeeping device for data processing. A few things will be different though. Waypoints in added transect segments will be numbered sequentially from the last one recorded before the obstacle. For example, if the last waypoint recorded before the end waypoint (i.e. 99) of transect 42 was 7, the start waypoint for transect 42.1 will be 8. Continue transect 42.1 per normal transect procedures. When you have completed transect 42.1 record the end waypoint as 99 just as you normally do. Once you return to the vehicle you will need to record only the return time and waypoint (i.e. 100) for transect 42. No drop off or return times or waypoints will be recorded for transect 42.1.

Transect live and carcass finds must be summarized for each segment (i.e., separately for transects 42 and 42.1. Opportunistic observations are not recorded under transect 42.1, however. Record all opportunistic observations of tortoises or carcasses under the original transect. In this example, record all opportunistic observations observed on this day under transect 42.

In summary, other than consecutively ordering waypoint numbers, not recording transect drop off and return information, and using the original transect to record opportunistic observations, these subsequent transects will be treated as completely new, they will have their own transect number, their own transect form on the RDA, and their own paper data sheets. This also means that at least one extra set of forms should be carried by crews at all times.

APPENDIX B: ESTIMATING G_0 AND ITS ASSOCIATED VARIANCE

The following is a complete white paper that was prepared by Linda Allison and circulated to USGS and UNR technical advisors to the monitoring program in September 2006. The general conclusions were applied in 2007, although the final approach did not focus on estimating G_0 for entire recovery units as described here, but for the smallest local area possible given the distribution of telemetry sites.

A Fundamental Assumption of Line Distance Sampling (LDS)

Not all tortoises in a population can be detected by transects, even if they are on the center of the transect line. Typically, these are either undetectable in deep burrows or well hidden in dense vegetation. The existence of a portion of the population that is "invisible" to sampling will bias the density estimates derived from LDS, but if the proportion of the population available for sampling can be estimated, then DISTANCE uses this parameter (G_0) to correct the bias. The fact that this quantity must be estimated means that it contributes variability to detection and therefore to density estimates. This estimation comes at the cost of decreased precision of the estimated abundance. The consideration of how this variance in G_0 is portioned at different spatial and temporal scales will factor into decisions of how G_0 may be pooled and whether indirect estimation techniques may work as well as direct ones.

Focal Animals

Estimation of G_0 consists of the establishment of a cohort of focal tortoises in each monitoring stratum. Most DWMAs within each RU stratum had an associated "focal population" of 5-20 animals (targeting at least 10 sub-/adults), ideally with equal numbers of males and females (Table A). The focal animals are equipped with radio transmitters and observed daily while transects are sampled in the associated DWMA. Contractors developed data sheets to document activity for focal tortoises, with some slight variations, and included the following information: transmitter frequency, GPS coordinates, general weather conditions, sex of the animal, time of day, temperature 1 cm above the ground, behavior (above or below ground or under a shrub), whether the animal was visible or not, signs of disease, etc.

How much does variance in G_0 affect variance in the density estimate?

Use of focal animals to assess G_0 is quite expensive, and there has been discussion of discontinuing this program in favor of indirect estimation of G_0. Indirect estimation might be less precise, but if variability in G_0 contributes little to the variance of density estimates, precision of these estimates will not be compromised. Although the analysis works with variances, the related quantity that is usually reported is the standard error, the square root of the variance.

In order to evaluate whether accurate estimation of G_0 is important to density estimation, I started with the variance components break-down for the 2005 DISTANCE analysis (Table A, highlighted row). The example is for an analysis stratifying by recovery unit, where components

are reported for Eastern Colorado. In 2005, the rangewide G_0 was 0.84 and G_0 SE was 0.018. I explored the effect of varying G_0 (first column) within the range of estimated values and the effect of varying the original estimated standard error by a factor of 5 or 10. This quick-and-dirty assessment was not comforting in that I suspected a 10-fold increase in the standard error of G_0 was within the range that might actually be expected, and at this level, the standard error of density was mostly a function of the variability in G_0. The last 2 columns of this table report range-wide density estimates for the same analyses, just to confirm the parallel with the original analysis. Note that variation in G_0 leads to changes in the estimate of density, as expected, but the variance in density is strictly a function of variance in G_0.

Table A. Component percentages of Var(D) as a function of G_0 and its standard error. The highlighted (7th) row of numbers indicates values used for 2005 analyses in USFWS (2006).

		Component of the variance in density (expressed as %)			Quantities of interest in USFWS (2006)	
G_0	Std Error(G_0)	Detection Probability (P_a)	Encounter rate (n/L)	G_0	Density	CV(Density)
0.64	0.018	11.1	86.3	2.6	7.5	0.09
0.64	0.09	6.8	53.1	40.1	7.5	0.16
0.64	0.18	3.1	24.1	72.8	7.5	0.29
0.74	0.018	11.1	86.9	2.0	6.5	0.08
0.74	0.09	7.6	59.1	33.3	6.5	0.15
0.74	0.18	3.8	29.5	66.7	6.5	0.26
0.84	0.018	11.5	87.0	1.5	5.8	0.08
0.84	0.09	8.4	63.7	27.9	5.8	0.14
0.84	0.18	4.6	34.7	60.7	5.8	0.23
0.94	0.018	11.2	87.6	1.2	5.1	0.08
0.94	0.09	8.7	67.7	23.7	5.1	0.13
0.94	0.18	5.1	39.6	55.4	5.1	0.21

Initial estimates of G_0

Each Program DISTANCE analysis accepts a single G_0 estimate. Under this sub-optimal situation, for the initial density estimates in 2001 through 2005, a single G_0 was estimated for each year, instead of separately for each DWMA or Recovery Unit. For each of the 57-119 telemetered animals each year with at least 10 observations, proportion visible was calculated as the proportion of observations where the tortoise was visible above ground or in a burrow. Overall annual G_0 was calculated as the mean over all tortoises of the individual proportion visible. The SEs were the SEs of these means.

Estimating G_0 to accurately reflect spatial and temporal variance

The above estimate of G_0 is not strictly accurate, since the goal is not to estimate the proportion of time that an individual is visible, but the proportion of the population that is visible. Generating this estimate across days within the same focal animal site, and then across sites within Recovery Units, allows estimation of G_0 as well as its variance at different spatial and temporal scales.

At any given site, all encounters with all telemetered tortoises were recorded (Table B). I used only the first observation of a tortoise on any date and limited the final date used to 1 June for 2001 and 2004, or 15 June for 2005, as described in the 2001-2005 report. The proportion visible on any date was the average of the 0/1 values (not visible/visible) at each site. At an extreme, if only one tortoise is detected at a site on a particular day, the resulting estimate of G_0 can only be 0 or 1. In order to maximize dates per site but also have a range of possible detection values, only those dates with at least 5 tortoise observations were used for each site (Table C). This removed 42 site-by-date combinations from consideration and left 590 for analysis (Table D).

Table B. Number of detections of a given tortoise on a single day. All detections of a tortoise were used in the original analysis. In the current analysis, only the first detection of each tortoise on a date was included.

Number of detections of a tortoise on a single day	Frequency of Tortoise X date combinations
1	2537
2	2341
3	588
4	166
5	46
6	22
7	9
8	0
9	1
Total	5710

Table C. Number of detected tortoises available for estimating G_0 for a given site X date combination. G_0 is initially estimated as the average of visible ("1") and not-visible ("0") tortoises, so the range of possible values is limited if there are few tortoises. Site X Date combinations were included in analysis if at least 5 tortoises were detected.

Number of tortoises detected	Frequency of Site X Date combinations
1	6
2	4
3	8
4	24
5	62
6	66
7	64
8	56
9	58
10	107
11	41
12	59
13	17
14	20
15	8
16	1
17	2
18	8
19	12
20	9
Total	632

Table D. Number of dates for which G_0 could be evaluated at each site each year

Recovery Unit	Focal Site	2001	2002	2003	2004	2005
Eastern Colorado	CK	20	11	8	12	12
Northern Colorado	CM	11		8	12	16
East Mojave	FE	0	9	0	0	0
	IV	0	10	0	8	3
	MP	22	0	0	0	0
	PB	7	11	12	8	12
	PM	12	10	15	9	33
	SV	5	0	0	0	0
	Total	25	51	35	37	60
Northeast Mojave	LS	13	14	9	6	0
	PB	4	0	0	0	10
	PM	0	0	1	0	0
	Total	17	14	10	6	10
Western Mojave	FK	26	16	8	0	0
	MC	31	5	7	4	5
	OR	10	18	11	6	6
	SC	19	27	14	10	14
	Total	86	66	40	20	25

Estimating G_0 across Recovery Units and years

There are three spatial scales of analysis (rangewide, Recovery Unit, focal site) and 2 temporal ones (years and days). I developed a model with Recovery Units as fixed effects but focal sites as random ones, nested within Recovery Units. Years were also treated as random effects, since the individual density estimates for each year are a sample of the year effects we are interested in. G_0 estimated once each day within sites was used to estimate within-site, between-date variation, also called "error variance."

Table E. Estimated marginal mean G_0 by Recovery Unit.

Recovery Unit	Mean	Standard Deviation	Standard Error
Eastern Colorado	0.773	0.078	0.021
Eastern Mojave	0.683	0.074	0.019
Northern Colorado	0.768	0.090	0.024
Northeastern Mojave	0.866	0.216	0.057
Western Mojave	0.863	0.047	0.012

Because there are different numbers of dates within focal sites, and the number of focal sites varies within Recovery Units and between years, ANOVA reports back estimated marginal means, which are more accurate but will not correspond exactly to simple averages. In Tables E and F, these estimated marginal means are reported with standard errors and standard deviations. Note that standard errors describe the distribution of *mean* G_0 given the factor of interest

(overall, by Recovery Unit, by year, etc.), whereas the standard deviation describes the dispersion of particular G_0's. In Table G, simple means and standard deviations are reported.

Table F. Estimated marginal mean G_0 by year.

Year	Mean	Standard Deviation	Standard Error
2001	0.854	0.075	0.018
2002	0.641	0.085	0.020
2003	0.811	0.086	0.021
2004	0.795	0.100	0.023
2005	0.795	0.096	0.021

Table G. Mean G_0 by year within recovery unit.

Recovery Unit	Year	Mean	Std Deviation	N (days with more than 5 tortoises)
Eastern Colorado	2001	0.930	0.056	20
	2002	0.775	0.163	11
	2003	0.893	0.101	8
	2004	0.596	0.162	12
	2005	0.655	0.155	12
Eastern Mojave	2001	0.747	0.280	32
	2002	0.724	0.145	29
	2003	0.769	0.263	26
	2004	0.825	0.124	20
	2005	0.875	0.156	40
Northern Colorado	2001	0.867	0.072	11
	2002			
	2003	0.858	0.084	8
	2004	0.854	0.104	12
	2005	0.684	0.199	16
Northeastern Mojave	2001	0.896	0.176	17
	2002	0.605	0.242	14
	2003	0.660	0.135	10
	2004	0.867	0.163	6
	2005	0.919	0.211	10
Western Mojave	2001	0.905	0.080	51
	2002	0.639	0.200	45
	2003	0.951	0.059	37
	2004	0.948	0.086	18
	2005	0.907	0.095	20

Estimating Var(G_0) and variance components

Using the same ANOVA model used above to test effects and estimate marginal means, I also ran a variance components analysis. Although Recovery Unit is theoretically a fixed effect (because values are reported for all Recovery Units of interest, not a random sample of them), operationally, we cannot use these separate estimates due to limitation of DISTANCE unless we use a different analysis for each Recovery Unit. In order to explore the relative value of separate analyses for years versus Recovery Units, the analysis treated Recovery Unit as a random variable.

Using this model, I estimated var(G_0) as well as the variance components attributable to variance between years, between Recovery Units, to variance attributable to the interaction between year and Recovery Unit, to sites within Recovery Units, and to different days within sites (the error variance). I used ANOVA and Restricted Maximum Likelihood (REML) methods to estimate variance components. They did not result in exactly comparable estimates (Table H).

The total variance estimated using the ANOVA estimation technique was much lower than that using REML. Also, the ANOVA estimation allows negative (non-sensical) variance estimates. These estimates correspond to very small (approaching zero) variances and are also zero when the *Recovery Unit X year* interaction is removed (not shown). In this case, the *Recovery Unit X year* combinations should be interpreted instead. Although there are general year-to-year patterns in variance, there are no strong patterns seen for Recovery Units. Instead, some Recovery Units vary more year-to-year than others.

The REML estimate is generally more robust, and allows development of confidence intervals for the variances. The ANOVA estimate is often informative because it produces variance estimates based on expected sums of squares, so parallels to the analysis for effect size estimation is possible.

Table H. Variance estimates using alternative estimation techniques.

Component	Estimate using ANOVA	Estimate using REML
Var(Year)	0.003	0.002
Var(Recovery Unit)	-0.006	0.001
Var(Recovery Unit X year)	0.008	0.010
Var(Site nested in Recovery Unit)	0.012	0.039
Var(Error) = Var(Day)	0.023	0.023
Total	0.046	0.075
Standard Deviation	0.214	0.274

Table I. Variance estimates using restricted maximum likelihood estimation techniques. Separate analyses each year.

Component	2001	2002	2003	2004	2005
Var(Recovery Unit)	.002	.000	.011	.015	.015
Var(Site nested in Recovery Unit)	.046	.012	.000	.002	.000
Var(Error) = Var(Day)	.015	.030	.026	.015	.025
Total	0.063	0.042	0.037	0.032	0.040
Standard Deviation	0.251	0.205	0.192	0.179	0.200

The ANOVA indicates that there is an important year X Recovery Unit interaction, so that annual visibility estimates did not go up and down in the same way for each Recovery Unit. This analysis did not assess whether visiting the Recovery Units in the same temporal sequence each year might remove this interaction effect. In other words, any attempts to "randomize" visits to transects in different Recovery Units might be making trend detection more difficult.

Due to this interaction effect, a separate analysis investigated within-year variance component patterns (Table I). In 2001 and 2002, the between focal-area variance was much more important than the between-Recovery Unit pattern. In subsequent years, the opposite was true.

Conclusions

Due to potential difficulties with precision of density estimates, the relatively large standard errors associated with G_0 may play an important estimate in developing useful density estimates. The actual variability seen in G_0 should lead to consideration of whether 1) transects within a Recovery Unit should be visited during a narrower window of time, potentially by concentrating efforts in one recovery unit at a time, 2) Due to the inherent variability in G_0, density estimates may be more accurate (if less precise) if analyses are customized for each year and each recovery unit or even each DWMA.

APPENDIX C: UPDATES TO TABLES 7 AND 8 OF THE 2001-2005 SUMMARY REPORT (USFWS 2006)

The current report is based on separate detection curves for teams with different levels of effort, spatially constructed estimates of G_0, different estimation of the standard error for G_0, and it estimates encounter rate first for each monitoring stratum before generating a recovery-unit-wide density estimate. These are the differences implemented for analysis since USFWS (2006) was written. This appendix reports stratum- and recovery-unit-level density estimates as a result of the same type of analysis applied to data from 2001 through 2005. Program DISTANCE was used to develop detection curves and develop encounter rate statistics reported below. When data are collected, crews report all tortoises detected, no matter how far from the line (training conditions them to focus close to the line, however). The first step in modeling the detection function is to "truncate" the data by determining the farthest distance for which observations will be modeled. Differences between truncation distance in USFWS (2006) and in the current analyses result in slight differences in the number of tortoises used in the analysis (n). Before 2007, monitoring sometimes extended late into June. Evaluating detection functions, USFWS (2006) concluded that this had a noticeable decrease in the proportion of tortoises detected, so date was included as a covariate in models. In contrast, during this reanalysis, models were more robust when they did not include data from these later periods. This is reflected in somewhat fewer observations and kilometers analyzed in 2003, in particular.

A remaining issue is the non-standard sampling frame each year, which resulted in over-sampling areas that were expected to have higher encounter rates. When densities in these areas were applied to the entire area of the monitoring strata, the resulting annual estimates were not appropriate. The reanalysis provided here does not address the fact that different landscapes were monitored each year, so density estimates are still not comparable between years. In upcoming evaluations, I anticipate using model-based estimation to correctly report the previous years of density estimates for the entire areas of interest and comparison year-to-year.

The analysis tables below are structured so that each year is represented by two tables. The first one documents the components of encounter rate, proportion visible, and detection rate. The second table in each pair provides the resulting density estimates at the stratum and recovery unit levels. In this latter table, the represented area for each stratum/recovery unit is reported. In years when the same stratum is representing a smaller area, this should be interpreted to mean that the density applies to a smaller, more homogeneous portion of the DWMA/critical habitat unit. In order to provide all of this information in only two tables for each year, G_0 sites and monitoring strata are abbreviated as in Table 13. Summary tables are in Tables 14-23.

Table 13. Abbreviations for transect strata and telemetry sites.

Abbreviation	Site name	Transect stratum	Telemetry site
AG	Chocolate Mountain Air Gunnery Range	X	
CM	Chemehuevi	X	X
CK	Chuckwalla	X	X
CS	Coyote Springs Valley	X	X
FE	Fenner	X	X
FK	Fremont-Kramer	X	X
GB	Gold Butte-Pakoon	X	
IV	Ivanpah	X	X
JT	Joshua Tree National Park	X	
MN	Lake Mead NRA North	X	
MS	Lake Mead NRA South	X	
LSTS	Large Scale Translocation Site		X
MC	Marine Corps Air Ground Combat Center (MCAGCC)	X	X
MP	Mojave National Preserve		X
MM	Mormon Mesa	X	
NS	Newberry Springs	X	
OR	Ord-Rodman	X	X
PT	Pinto Mountains	X	
PT2	Pinto Mountains (non-critical habitat)	X	
PB	Piute (Border)		X
PM	Piute Mid		X
PI	Piute-Eldorado	X	
SV	Shadow Valley		X
SC	Superior Cronese	X	X

Table 14. 2001 estimates of encounter rates, proportion of tortoises that were visible, and detection rates.

Encounter rate (n/L)							Proportion of tortoises visible to be counted (G_0)					Detection rate (P_a)				
Stratum	*Start date*	*End date*	*Transects (k)*	*Kilometers walked (L)*	*Tortoises (n)*	*CV(n/L)*	*Telemetry sites*	*Start date*	*End date*	G_0	$CV(G_0)$	*Data collection group(s)*	*Truncation distance (m)*	*Effective strip half-width (m)*	P_a	$CV(P_a)$
CM	1-Apr	11-Apr	189	302	36	17.9	CM	1-Apr	11-Apr	0.84	11.3	Kiva + Mojave Natl Preserve	18	9.9	0.55	8.2
CK	23-Apr	16-May	204	326	60	15.0	CK	23-Apr	16-May	0.92	6.7					
FE	21-May	13-Jun	20	31	6	48.9	MP	21-May	13-Jun	0.61	38.4					
IV	24-Apr	29-May	117	185	7	36.8	SV + MP	23-Apr	29-May	0.68	49.7					
PI	23-Apr	16-May	71	124	5	51.2	PM + PB	11-Apr	18-Jun	0.88	19.4	UDWR + Chambers + UNR	18	10.9	0.61	8.0
BD	4-Jun	19-Jun	47	57	5	43.0	LSTS	4-Jun	19-Jun	0.72	36.7					
CS	17-Apr	25-Jun	51	99	4	49.4	LSTS	17-Apr	25-Jun	0.86	20.5					
GB	10-May	22-Jun	65	137	3	56.0										
MM	23-Apr	16-May	47	87	3	57.0										
FK	4-Apr	11-May	211	338	36	17.1	FK + SC + OR	3-Apr	24-May	0.89	14.1					
SC	3-Apr	24-May	211	338	28	19.7										
OR	15-Apr	24-May	197	315	56	14.3						Kiva + Mojave Natl Preserve	18	9.9	0.55	8.2
JT	13-Apr	17-May	77	123	13	25.5	MC	12-Apr	25-May	0.92	9.7					
PT	12-Apr	12-May	80	128	15	30.1										
MC	19-Apr	25-May	90	144	21	24.5										

In USFWS (2006), the single G_0 (with incorrectly calculated %CV) for 2001 was 0.868 (1.5). The single P_a to 15m (with %CV) was 0.585 (3.9)

Four monitoring strata that are not part of DWMAs were monitored in 2001. Lake Mead South and Mojave National Preserve each reported only 1 live observation that was not smaller than 180mm. The single tortoise found at Lake Mead North was smaller than the threshold size. Stratum-level density estimates were therefore not estimated. No tortoises were seen on transects at Edwards Air Force Base (non-critical habitat that was surveyed very late in the season in mid-June. Transects at MCAGCC are also outside of long-term monitoring strata and critical habitat. However, sufficient tortoises over 180mm MCL were encountered (n=15) to estimate density for this stand-alone stratum. This density was not used in the Western Mojave Recovery Unit estimate, however.

Table 15. 2001 density estimates for monitoring strata and recovery units

Stratum density (*D*, tortoises/km^2)						Recovery unit density (*D*, tortoises/km^2)					
Stratum	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*	*Recovery unit*	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*
CM	2989	7.2	22.6	4.64	11.15	Northern Colorado	2989	7.2	22.6	4.64	11.15
CK	2861	10.1	18.3	7.04	14.36	Eastern Colorado	2861	10.1	18.3	7.04	14.36
FE	1383	15.7	62.7	5.08	48.61	Eastern Mojave	4901	6.2	46.6	2.62	14.87
IV	1991	2.8	62.3	0.92	8.69						
PI	1527	2.1	55.4	0.76	5.78						
BD	773	5.6	57.1	1.98	15.91	Northeastern Mojave	3775	2.4	34.8	1.22	4.60
CS	529	2.2	54.1	0.80	5.80						
GB	1603	1.2	60.2	0.39	3.47						
MM	870	1.8	61.1	0.61	5.55						
FK	1403	5.5	23.6	3.47	8.64	Western Mojave	5615	5.6	13.8	4.32	7.39
SC	2136	4.3	25.5	2.60	6.97						
OR	601	10.1	21.7	6.62	15.33						
JT	1035	5.8	28.4	3.37	10.07						
PT	440	6.5	32.7	3.46	12.09						
MC	2030	8.1	27.6	4.74	13.69						

Table 16. 2002 estimates of encounter rates, proportion of tortoises that were visible, and detection rates.

Encounter rate (n/L)							Proportion of tortoises visible to be counted (G_0)					Detection rate (P_a)				
Stratum	*Start date*	*End date*	*Transects (k)*	*Kilometers walked (L)*	*Tortoises (n)*	*CV(n/L)*	*Telemetry sites*	*Start date*	*End date*	G_0	$CV(G_0)$	*Data collection group(s)*	*Truncation distance (m)*	*Effective strip half-width (m)*	P_a	$CV(P_a)$
CK	2-May	19-May	104	417	42	19.3	CK	3-May	19-May	0.76	20.5	Kiva	16	8.6	0.54	5.9
FE	15-Apr	3-May	73	293	14	34.7	FE + IV	15-Apr	3-May	0.75	19.8					
IV	24-Apr	1-May	112	446	31	21.1										
PI	16-Apr	21-May	98	377	11	33.8	PM + PB	16-Apr	21-May	0.70	31.2	UDWR + Chambers + UNR	16	8.9	0.56	8.1
BD	16-Apr	17-May	27	107	0	0	LSTS*	23-Apr	26-Apr	0.71	26.7					
CS	22-Apr	23-Apr	12	46	2	66.8										
GB	24-Apr	25-Apr	12	48	0	0										
MM	18-Apr	6-May	24	94	0	0										
FK	13-Apr	1-May	129	512	33	24.0	FK	13-Apr	30-Apr	0.78	17.2					
SC	1-Apr	19-May	171	677	51	16.0	SC	1-Apr	19-May	0.52	41.6					
OR	2-Apr	10-May	106	424	71	13.1	OR	2-Apr	10-May	0.75	17.6	Kiva	16	8.6	0.54	5.9
JT	18-Apr	26-Apr	39	156	8	54.3	MC	18-Apr	24-Apr	0.91	6.6					
PT	8-Apr	11-Apr	48	192	12	30.4										
MC	18-Apr	24-Apr	40	160	15	32.7										

In USFWS (2006), the single G_0 (with incorrectly calculated %CV) for 2002 was 0.708 (4.3). The single P_a to 15m (with %CV) was 0.565 (4.1)

*The LSTS telemetry site was monitored for a longer period, but since only CS transect data were analyzed (see below), the analyzed telemetry dates were trimmed to match those when transects were walked in CS.

Transects at MCAGCC are outside of long-term monitoring strata and critical habitat. However, sufficient tortoises over 180mm MCL were encountered (n=18) to estimate density for this stand-alone stratum. This density was not be part of the Western Mojave Recovery Unit estimate, however.

No monitoring occurred in the Northern Colorado Recovery Unit. Although transects were walked in the Northeastern Mojave, only 2 tortoises were seen over 180mm. Both of these were in the Coyote Springs Valley stratum; no separate estimate is available for the other 3 strata in this recovery unit. No recovery unit estimate was calculated for the Northeastern Mojave in 2002.

The numbers of observed tortoises do not tell all. As an example, transects in Beaver Dam Slope were walked throughout the stratum, whereas transects walked in Coyote Springs Valley and Mormon Mesa were completed in localized areas less than one-fourth of the area in those monitoring strata. In Gold Butte, the transects were packaged into an area less than one-tenth as large as the stratum. This is an example of how density estimates should not be viewed as representative of the larger stratum for this year.

Table 17. 2002 density estimates for monitoring strata and recovery units.

Stratum density (*D*, tortoises/km^2)						Recovery unit density (*D*, tortoises/km^2)					
Stratum	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*	*Recovery unit*	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*
CK	1531	7.7	28.8	4.44	13.41	Eastern Colorado	1531	7.7	28.8	4.44	13.41
FE	1259	3.7	40.4	1.73	7.96	Eastern Mojave	3234	4.1	22.1	2.64	6.22
IV	1240	5.4	29.5	3.07	9.53						
PI	735	2.3	46.7	0.98	5.60						
CS	152	3.5	72.4	0.98	12.46	Northeastern Mojave					
FK	458	4.7	30.6	2.59	8.37	Western Mojave	1595	5.8	24.2	3.66	9.31
SC	545	8.1	45.2	3.49	18.96						
OR	68	13.1	22.7	8.43	20.31						
JT	332	3.3	55.0	1.20	8.97						
PT	192	4.0	31.7	2.18	7.32						
MC	1052	6.0	33.9	3.14	11.41						

Table 18. 2003 estimates of encounter rates, proportion of tortoises that were visible, and detection rates.

Encounter rate (n/L)							Proportion of tortoises visible to be counted (G_0)					Detection rate (P_a)				
Stratum	*Start date*	*End date*	*Transects (k)*	*Kilometers walked (L)*	*Tortoises (n)*	*CV(n/L)*	*Telemetry sites*	*Start date*	*End date*	G_0	$CV(G_0)$	*Data collection group(s)*	*Truncation distance (m)*	*Effective strip half-width (m)*	P_a	$CV(P_a)$
FK	7-Apr	31-May	130	519	43	17.9	FK	14-Apr	31-May	0.96	6.19	Kiva - West Mojave	22	12.5	0.57	4.0
OR	8-Apr	21-Apr	166	663	63	15.4	OR	8-Apr	21-Apr	0.97	3.66					
SC	22-Apr	1-Jun	127	506	96	11.8	SC	22-Apr	1-Jun	0.93	7.36					
JT	30-Apr	4-May	50	200	13	26.5	MC	26-Apr	3-May	0.96	7.43					
PT	26-Apr	30-Apr	49	196	18	24.7										
CK	3-May	14-May	106	424	35	19.4	CK	3-May	14-May	0.92	10.57	Kiva - Colorado	20	11.1	0.56	5.4
CM	3-May	21-May	112	445	53	18.1	CM	4-May	19-May	0.86	8.08					
CS	14-Apr	11-Jun	40	157	14	21.6	LSTS + PM + PB	24-Apr	17-Jun	0.71	39.32	UNR	20	11.4	0.57	7.6
GB	30-Apr	17-Jun	70	238	7	41.0										
MM	24-Apr	28-Jun	77	296	18	26.0										
PI	23-Apr	29-May	48	171	11	36.82	PM + PB	21-Apr	29-May	0.89	23.40					

In USFWS (2006), the single G_0 (with incorrectly calculated %CV) for 2003 was 0.874 (2.1). The single P_a to 15m (with %CV) was 0.707 (3.0).

Not all of the conventional strata were surveyed in the Northeastern Recovery unit, so the density cannot be meaningfully compared to other years. Only one of four strata in the Eastern Mojave was surveyed, so no estimate is possible at the level of the recovery unit.

Table 19. 2003 density estimates for monitoring strata and recovery units.

Stratum density (*D*, tortoises/km^2)						Recovery unit density (*D*, tortoises/km^2)					
Stratum	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*	*Recovery unit*	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*
FK	458	3.4	19.4	2.36	5.01						
OR	545	4.1	17.5	2.92	5.77						
SC	68	7.8	13.0	6.05	10.04						
JT	332	2.7	27.8	1.59	4.65						
PT	192	3.8	26.1	2.32	6.35	Western Mojave	1595	3.8	10.6	3.05	4.61
CK	1531	4.0	22.7	2.61	6.28	Eastern Colorado	1531	4.0	22.7	2.61	6.28
CM	2484	6.3	20.6	4.20	9.33	Northern Colorado	2484	6.3	20.6	4.20	9.33
CS	152	5.5	45.5	2.37	12.98						
GB	162	1.8	57.3	0.65	5.22	Northeastern Mojave	572	3.7	43.1	1.65	8.30
MM	258	3.8	47.7	1.56	9.20						
PI	735	3.2	44.3	1.38	7.27	Eastern Mojave*					

*Only one of four strata in the Eastern Mojave was surveyed, so no estimate is possible at the level of the recovery unit.

Table 20. 2004 estimates for encounter rates, proportion of tortoises that were visible, and detection rates.

Encounter rate (n/L)							Proportion of tortoises visible to be counted (G_0)					Detection rate (P_a)				
Stratum	*Start date*	*End date*	*Transects (k)*	*Kilometers walked (L)*	*Tortoises (n)*	*CV(n/L)*	*Telemetry sites*	*Start date*	*End date*	G_0	$CV(G_0)$	*Data collection group(s)*	*Truncation distance (m)*	*Effective strip half-width (m)*	P_a	$CV(P_a)$
FK	6-Apr	24-Apr	41	463	47	19.8	SC + OR	2-Apr	26-Apr	0.96	7.1	Kiva	14	8.46	0.60	3.3
SC	2-Apr	25-Apr	62	690	52	21.1										
OR	4-Apr	26-Apr	35	381	33	24.3										
JT	12-Apr	3-May	23	278	8	29.2	MC	12-Apr	3-May	0.98	2.9					
PT	2-May	2-May	5	56	2	98.1										
CK	8-Apr	10-May	132	1414	108	11.9	CK	8-Apr	10-May	0.70	26.1					
CM	13-Apr	1-May	76	836	84	14.7	IV + PM + PB	13-Apr	4-Jun	0.86	17.1					
FE	16-Apr	28-Apr	37	410	52	20.6										
IV	17-Apr	12-May	43	515	35	24.2										
PI	14-Apr	4-Jun	70	686	32	21.6						UNR	20	9.92	0.50	10.5
BD	15-Jun	16-Jun	10	100	0	0										
CS	23-Apr	4-Jun	37	365	8	36.3										
GB	21-Apr	19-May	37	361	4	48.1										
MM	23-Apr	16-May	31	311	12	30.9										

In USFWS (2006), the single G_0 (with incorrectly calculated %CV) for 2004 was 0.864 (2.1). The single P_a to 12m (with %CV) was 0.647 (2.8).

All surveyed strata for 2004 are long-term monitoring strata. Most had sufficient detections to estimate stratum-level densities. Although 10 transects were walked in Beaver Dam Slope, these were completed in mid-June, and no tortoises were detected. No stratum level estimate is possible, so these later transects did not affect the decision to limit analysis to transects on and before 4 June. The Northeastern Mojave Recovery Unit density estimate does not reflect information in Beaver Dam Slope.

Table 21. 2004 density estimates for monitoring strata and recovery units.

Stratum density (*D*, tortoises/km^2)						Recovery unit density (*D*, tortoises/km^2)					
Stratum	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*	*Recovery unit*	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*
FK	2070	6.1	20.2	3.77	9.93	Western Mojave	7911	4.4	13.0	3.40	5.64
SC	3087	4.5	21.5	3.02	6.82						
OR	836	5.2	24.7	2.84	9.57						
JT	1313	1.7	29.6	1.29	2.33						
PT	605	2.2	98.2	0.17	27.52						
CK	4137	6.4	28.9	3.70	11.22	Eastern Colorado	4137	6.4	28.9	3.70	11.22
CM	3789	6.9	22.8	4.46	10.78	Northern Colorado	3789	6.9	22.8	4.46	10.78
FE	1833	8.7	27.0	2.79	27.33	Eastern Mojave	6017	5.3	20.0	3.56	7.74
IV	2112	4.7	29.9	2.14	10.29						
PI	2072	2.7	29.5	1.73	4.35						
CS	638	1.3	41.5	0.84	1.98	Northeastern* Mojave	3518	1.2	30.1	0.68	2.15
GB	1923	0.7	52.1	0.46	0.92						
MM	957	2.3	36.9	1.26	4.10						

*Estimate of density does not include information for Beaver Dam Slope.

Table 22. 2005 estimation of encounter rates, proportion of tortoises that were visible, and detection rates.

Encounter rate (n/L)							Proportion of tortoises visible to be counted (G_0)					Detection rate (P_a)				
Stratum	*Start date*	*End date*	*Transects (k)*	*Kilometers walked (L)*	*Tortoises (n)*	*CV(n/L)*	*Telemetry sites*	*Start date*	*End date*	G_0	$CV(G_0)$	*Data collection group(s)*	*Truncation distance (m)*	*Effective strip half-width (m)*	P_a	$CV(P_a)$
CK	22-Apr	31-May	91	1094	77	16.0	CK	22-Apr	31-May	0.74	20.5	Kiva	14	6.0	0.43	6.1
CM	28-Apr	7-Jun	94	1129	95	12.1	CM	28-Apr	7-Jun	0.65	26.6					
FK	14-Apr	20-May	56	673	41	19.2	OR + SC	16-Apr	24-May	0.92	9.8					
SC	16-Apr	23-May	84	1009	72	15.8										
OR	21-Apr	24-Apr	26	310	27	18.9										
JT	24-Apr	14-May	50	601	18	23.5	MC	23-Apr	14-May	0.90	12.2					
PT	23-Apr	14-May	13	155	17	33.4										
FE	2-May	6-May	24	288	42	15.9	IV	2-May	7-May	0.87	11.7					
IV	4-May	7-Jun	14	168	8	54.2										
PI	12-Apr	10-Jun	95	1062	59	14.0	PM + PB	12-Apr	10-Jun	0.90	15.8	UNR	18	7.2	0.40	10.0
MS	5-May	9-Jun	23	228	5	38.8										
BD	13-Apr	9-Jun	40	421	5	50.8										
CS	12-Apr	8-Jun	22	237	10	34.0										
GB	12-Apr	7-Jun	43	432	1	100.1										
MM	21-Apr	3-Jun	36	398	25	23.2										
MN	5-May	9-Jun	12	117	4	42.4										

In USFWS (2006), the single G_0 (with incorrectly calculated %CV) for 2005 was 0.840 (2.1). The single P_a to 12m (with %CV) was 0.525 (3.1).

All monitored strata reported enough observations to estimate stratum-specific densities. Two monitoring strata that are not part of DWMAs were monitored this year. Lake Mead North and Lake Mead South densities were not included in estimates of Northeastern Mojave and Eastern Mojave recovery unit densities, respectively.

Table 23. 2005 density estimates for monitoring strata and recovery units.

Stratum density (*D*, tortoises/km^2)						Recovery unit density (*D*, tortoises/km^2)					
Stratum	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*	*Recovery unit*	*Area (km^2)*	*D*	*CV(D)*	*95% CI for D Lower Limit*	*95% CI for D Upper Limit*
CK	4199	7.9	26.7	4.73	13.24	Eastern Colorado	4199	7.9	26.7	4.73	13.24
CM	4038	10.8	29.9	6.07	19.10	Northern Colorado	4038	10.8	29.9	6.07	19.10
FK	2405	5.7	25.6	3.48	9.34	Western Mojave	9358	6.1	17.2	4.36	8.52
SC	3447	6.7	23.1	4.26	10.44						
OR	1124	8.1	25.3	5.00	13.28						
JT	1774	2.8	28.9	1.61	4.88						
PT	608	10.3	37.4	5.05	20.89						
FE	1857	14.0	20.6	9.36	20.82	Eastern Mojave	6371	7.2	20.1	4.90	10.67
IV	2565	4.6	55.7	1.64	12.63						
PI	1949	4.3	23.3	2.76	6.80						
MS	824	1.7	43.1	0.76	3.84						
BD	828	0.9	54.1	0.34	2.50	Northeastern Mojave	4537	1.8	25.8	1.12	3.04
CS	762	3.3	38.8	1.58	6.86						
GB	1977	0.2	101.8	0.03	0.94						
MM	970	4.9	29.8	2.76	8.67						
MN	1552	2.7	46.3	1.13	6.33						

APPENDIX D: ORIGINAL AND RECALCULATED RECOVERY UNIT DENSITY ESTIMATES, 2001 TO 2005

As described in this report, the standard error used in USFWS (2006) for G_0 was miscalculated. The resulting coefficient of variation (CV = standard error/estimate) was too small, and resulted in smaller confidence intervals than were appropriate. Also, in order to simplify use of the software DISTANCE, only one G_0 estimate was created for each year.

Although the correct calculation of the standard error for G_0 has the effect of decreasing apparent precision, other parts of the reanalysis added precision to the density estimates. By providing more customized estimates of G_0 for smaller areas, by developing separate detection curves for each monitoring group, and by estimating encounter rates for each stratum instead of each of the larger recovery units, the new analysis provides the optimum precision available for each year's study design. In general, Table 24 reports only slightly reduced precision between the original analysis and the current one.

Another pattern that can be seen in the table is the annually improving precision of density estimates within each recovery unit. This is a reflection of the increasing effort (kilometers walked) that planners implemented to improve estimates of encounter rate. The improved precision reflects an approximately 3-1/2-fold increase in the number of kilometers walked since the first year of this program (see tables in Appendix C).

The areas sampled in each recovery unit changed from year to year, and this is also reported in Table 24. When areas sampled in a given recovery unit are smaller, this also translates into a more restricted type of habitat, and may best reflect densities of tortoises in optimal habitat in that recovery unit. Since 2004, the sampling frame has been expanded to sample all of a given DWMA; however, sampling in rugged terrain has not been consistent.

Table 24. Comparison of original density estimates (USFWS 2006) with corrected estimates in this report.

	USFWS (2006)				95% Confidence Interval		Revised in this report		95% Confidence Interval	
Recovery Unit	**Year**	**Sampled area (km^2)**	**Density ($/km^2$)**	**%CV(Density)**	**Lower Limit**	**Upper Limit**	**Density (km^2)**	**%CV(Density)**	**Lower Limit**	**Upper Limit**
Northeastern Mojave	2001	3775	2.3	34.0	1.20	4.45	2.4	34.8	1.22	4.60
	2002	152	0.8	56.6	0.29	2.40	*			
	2003	572	3.0	15.4	2.22	4.08	3.7	43.1	1.65	8.30
	2004	3518	1.4	24.2	0.88	2.27	1.2	30.1	0.68	2.15
	2005	4537	2.2	18.6	1.50	3.10	1.8	25.8	1.12	3.04
	2007	4917					1.7	25.0	1.04	2.73
Eastern Mojave	2001	4901	3.0	26.2	1.81	4.98	6.2	46.6	2.62	14.87
	2002	3234	4.1	17.0	2.94	5.72	4.1	22.1	2.64	6.22
	2003	735	2.8	31.7	1.49	5.12	*			
	2004	6017	5.6	13.4	4.28	7.26	5.3	20.0	3.56	7.74
	2005	6371	5.5	11.8	4.39	6.99	7.2	20.1	4.90	10.67
	2007	6681					5.8	25.0	3.56	9.34
Eastern Colorado	2001	2861	10.8	15.9	7.91	14.73	10.1	18.3	7.04	14.36
	2002	1531	8.3	20.2	5.58	12.30	7.7	28.8	4.44	13.41
	2003	1531	4.0	19.3	2.74	5.85	4.0	22.7	2.61	6.28
	2004	4137	5.4	12.7	4.18	6.91	6.4	28.9	3.70	11.22
	2005	4199	6.4	16.6	4.60	8.86	7.9	26.7	4.73	13.24
	2007	4263					5.0	22.6	3.21	7.72
Northern Colorado	2001	2989	8.0	17.5	5.65	11.19	7.2	22.6	4.64	11.15
	2002						*			
	2003	2484	6.6	17.1	4.67	9.17	6.3	20.6	4.20	9.33
	2004	3789	7.0	15.6	5.17	9.59	6.9	22.8	4.46	10.78
	2005	4038	7.9	12.8	6.11	10.12	10.8	29.9	6.07	19.10
	2007	4038					4.6	43.4	2.03	10.31

Table 24. (continued)

	USFWS (2006)				95% Confidence Interval		Revised in this report		95% Confidence Interval	
Recovery Unit	**Year**	**Sampled area (km^2)**	**Density (/km^2)**	**%CV(Density)**	**Lower Limit**	**Upper Limit**	**Density (km^2)**	**%CV(Density)**	**Lower Limit**	**Upper Limit**
Western Mojave	2001	5615	7.6	9.4	6.31	9.11	5.6	13.8	4.32	7.39
	2002	1595	7.1	10.6	5.77	8.73	5.8	24.2	3.66	9.31
	2003	1595	5.7	8.8	4.75	6.72	3.8	10.6	3.05	4.61
	2004	7911	5.3	12.5	4.15	6.78	4.4	13.0	3.40	5.64
	2005	9358	6.0	10.3	4.86	7.28	6.1	17.2	4.36	8.52
	2007	9298					4.7	30.8	2.62	8.51

*In the Northeastern Mojave, there are 4 long-term monitoring strata. Only CS could be analyzed in 2002, while in 2003 and 2004, BD could not be analyzed. No recovery unit estimate is provided for 2002, and the 2003 and 2004 estimates are based on 3 of 4 strata. In the Eastern Mojave, only one of the three strata (Piute-Eldorado) was surveyed in 2003, so no estimate is provided for the recovery unit. The single stratum in the Northern Colorado Recovery Unit was not surveyed in 2002.

PROGRESS REPORT FOR 2009

The Health Status of Translocated Desert Tortoises (*Gopherus agassizii*) in the Fort Irwin Translocation Area and Surrounding Release Plots, San Bernardino County, California: Year 2

Timothy Gowan and Kristin H. Berry (Principal Investigator)
U. S. Geological Survey
Western Ecological Research Center
22835 Calle San Juan de Los Lagos
Moreno Valley, California 92553

for

Commander National Training Center and Fort Irwin
ATTN: AFZJ-PW-EV, Mr. Clarence Everly
P.O. Box 105097
Fort Irwin, CA 92310-5097

The Health Status of Translocated Desert Tortoises (*Gopherus agassizii*) in the Fort Irwin Translocation Area and Surrounding Release Plots, San Bernardino County, California

Abstract. In spring of 2008, we translocated 158 adult and subadult tortoises (82 females and 76 males) from the Southern Expansion Area (SEA) to four plots located in the Superior-Cronese Desert Wildlife Management Area (DWMA) as part of the Desert Tortoise Health and Disease Research Project for the Ft. Irwin Expansion. Long-term objectives include modeling and predicting effects of translocation on survival of tortoises by health status, presence of infectious diseases and trauma, size and age class, and sex. Tortoises were placed in 4 health categories: 1) healthy or control tortoises, 2) tortoises with moderate to severe clinical signs of past trauma, 3) tortoises with moderate to severe clinical signs of shell disease, and 4) tortoises with moderate to severe clinical signs of upper respiratory tract disease but with no evidence of nasal discharge and negative laboratory tests.

As of December 2008, 43 of the initial 158 translocated tortoises had been found dead or had been salvaged for necropsy, and an additional 15 tortoises were missing. We started Year 2 in January 2009, with 100 live tortoises and 15 missing tortoises in the project. During 2009, we conducted health evaluations for clinical signs of health, disease, and trauma for 81 tortoises in the spring and 65 tortoises in the fall. In the spring 4 (4.9%) and 2 (2.5%) tortoises had positive or suspect ELISA tests for *Mycoplasma agassizii* and *M. testudineum,* respectively. In the fall 6 of 65 (9.2%) tortoises tested positive or suspect for *M. agassizii*; none had positive or suspect tests for *M. testudineum*. Overall during 2009, 9 of 81 individual tortoises (11.1%) had ELISA test results that were positive or suspect for *Mycoplasma* species. When weights of tortoises were compared for 2008 and 2009, spring weights were significantly higher than fall weights. In addition, weights in fall 2009 were significantly lower than weights in fall 2008.

Between January and December of 2009, 27 (23.5%) of the remaining 115 live and missing tortoises were found dead. Of the 27, 24 were probably killed by coyotes or other canids, one was killed by a vehicle, and 2 died of unknown causes. Overall, since the translocation began in March of 2008, 44.3% of tortoises have been found dead or were salvaged for necropsy. Combining data from 2008 and 2009, death rates were significantly higher on two plots, plots 3 and 5, than on plots 1.5 and 8. In contrast to 2008, in 2009 the size of a tortoise was not related to risk of death; the average carapace length did not differ from those still alive. Likewise, in contrast to 2008, in 2009 death rates did not differ between sexes. Death rates also did not differ significantly among the four health categories. At the end of 2009, an additional 20 tortoises (17.4%, 20/115) were missing.

We analyzed movement patterns for live tortoises between the time of initial release in spring 2008 and December 2009 (N = 68). Overall, the mean dispersal distance for males was twice that of females; likewise, males moved twice the total distances compared to females. Total distances moved were higher on plots 3 and 5 than

on plots 1.5 and 8 but were not significantly different. However, the minimum total distances moved in 2009 were significantly less than in 2008. Females were more likely to use the same cover sites between 2008 and 2009 than males, a potential indication of settling.

INTRODUCTION

The desert tortoise (*Gopherus agassizii*) is a Federally- and State-listed threatened species. Critical habitat for the species occurs north and west of the Colorado River/Grand Canyon complex, including habitat on and adjacent to the National Training Center, Ft. Irwin, in the central Mojave Desert (U.S. Fish and Wildlife Service 1990, 1994). As part of the Ft. Irwin Translocation Project, an estimated 600 to 1000 tortoises have been or are planned to be translocated from the southern and western parts of the expanded Ft. Irwin base to areas outside the Ft. Irwin boundary (Esque et al. 2005).

The primary goal of this research project is to monitor the health and disease status of the translocated tortoises, with an emphasis on the spread of infectious disease. Because infectious diseases have been linked to declining desert tortoise populations (Jacobson et al. 1991; Brown et al. 1994, 1999; Homer et al. 1998; Christopher et al. 2003), the incidence of disease is a critical factor in determining success of translocation. We designed our project to measure the success of translocation, depending on health status of translocated tortoises. Specifically, the translocated tortoises were grouped into one of four health categories: 1) healthy or control tortoises, without moderate to severe clinical signs of infectious disease, trauma, or shell disease; 2) tortoises with moderate to severe clinical signs of past trauma; 3) tortoises with moderate to severe clinical signs of shell disease; and 4) tortoises with moderate to severe clinical signs of upper respiratory tract disease (URTD), but with no evidence of nasal discharge and negative laboratory tests.

Several long-term objectives are to be addressed during the life of the multi-year project. First, we are tracking and sampling tortoises for several years to model and predict the effects of translocation on survival by health status, size and age class, and sex. More specifically, we hope to determine whether or not translocatees in each of the four health categories develop new disease, more severe clinical signs of URTD, more severe cases of shell disease, or new trauma post-translocation. To better understand the epidemiology and distribution of mycoplasmosis or URTD in the Ft. Irwin Translocation Project area, the health status of tortoises and locations of tortoises that have previously tested positive or suspect for mycoplasmosis are being continuously monitored. As part of these analyses, we are also examining differences in survivorship and causes of death among health status categories; differences in survivorship among size and age classes, sexes, and translocation release sites; and differences in the pathogenesis of mycoplasmosis among size and age classes, sexes, and levels of anthropogenic impacts.

Second, the anthropogenic factors most likely to influence translocation success need to be identified and modeled. Anthropogenic factors include but are not limited to

roads, military maneuver areas, and rural or urban areas. Third, ecological factors, including landscape and topography, are other variables in the analysis. Both anthropogenic and ecological factors have the potential of affecting health status and degree of trauma of translocated tortoises. We will also explore differences in survivorship among size and age classes and sexes by comparing habitat conditions between initial capture sites and translocation release sites, including levels of anthropogenic disturbance at original home sites and release sites.

This report is a progress report summarizing the status of 158 tortoises that were translocated in the spring of 2008 and were subsequently monitored for health and disease (Berry et al. 2009). Briefly, in spring of 2008, a total of 82 females and 76 males were translocated from the Southern Expansion Area (SEA) to four plots located in the Superior-Cronese Desert Wildlife Management Area (DWMA). As of December 2008, 43 of the initial 158 translocated tortoises had been found dead (41) or salvaged for necropsy (2), and an additional 15 tortoises were unable to be located and were considered missing. We started the 2009 field season in January with 100 remaining tortoises. In addressing the previously stated objectives, we tracked the remaining translocated tortoises monthly, continued to search for missing tortoises, conducted health evaluations on the tortoises during spring and fall, analyzed movement patterns and use of cover sites, and determined causes of death for dead individuals. Our preliminary findings for 2009 are summarized below.

METHODS

Translocation

Between March 26 and April 8, 2008, 158 desert tortoises were translocated from the SEA to one of four designated plots (plots 1.5, 3, 5, and 8; see Fig. 1). These translocation plots, each about one square mile in size, are located outside the Ft. Irwin boundary and are within or bordering the Superior-Cronese DWMA. Prior to translocation, tortoises located in the SEA were fitted with radiotransmitters and were assigned to one of the following four health status categories based on previous health evaluations: 1) healthy tortoises, without moderate to severe clinical signs of infectious disease, trauma, or shell disease; 2) tortoises with moderate to severe clinical signs of past trauma; 3) tortoises with moderate to severe clinical signs of shell disease; and 4) tortoises with moderate to severe clinical signs of URTD, but with no evidence of nasal discharge and negative laboratory tests. Approximately 20 adult males and 20 adult females in each of the four health status categories were selected to be translocated (Berry et al. 2009). Tortoises that had previously tested positive for mycoplasmosis or had signs of nasal discharge were not considered for translocation.

Tortoises were tracked daily, then weekly, and finally at least once per month after translocation using radio telemetry (Berry et al. 2009). Beginning in July 2008, all translocated tortoises were tracked on a monthly basis, unless behavioral or health reasons dictated more frequent checks. Upon locating tortoises during monthly tracking, critical data were recorded, including, but not limited to: date, weather conditions, time

observed, location in UTMs (NAD 83), behavioral observations, specific location of the tortoise (e.g., inside cover site, in open, under shrub), interactions with other tortoises, and general condition of the tortoise (e.g. appearing ill, stressed, lethargic, or healthy). When tortoises were located and found to be dead, the location, position, and condition of remains, along with evidence for cause of death were recorded and the remains were photographed.

Health Evaluations

Periodically, comprehensive health evaluations of each tortoise were conducted. In general, the health status of each tortoise was evaluated once in the spring (April 27 to May 4) and once in the fall (October 7 to October 27) in 2009, but these evaluations were more frequent for tortoises showing indications of illness or stress. The evaluations included recording data regarding posture, behavior, activity, recent trauma, and clinical signs of disease, such as URTD and cutaneous dyskeratosis, on the eyes, beak, nares, integument, and shell on a standardized seven-page form modified from an appendix in Berry and Christopher (2001). Length at the carapace midline (MCL) and weight of each tortoise were measured during evaluations, and digital photographs were taken of the eyes, beak, nares, plastron, carapace, and any unusual trauma or lesions. Blood and nasal lavage samples were also collected during health evaluations.

Samples of blood were drawn either by brachial venipuncture or from the subcarapacial site using standard protocols (Hernandez-Divers et al. 2002, Berry et al. 2006). Samples of blood that contained 15% or more of lymph were considered to be suboptimal because of the potential negative impact of dilution (e.g., Gottdenker and Jacobson 1995). Where possible, such samples were repeated with an objective of obtaining 90–100% blood with no lymph or only a trace of lymph (Berry et al. 2005). A nasal lavage was taken using standard protocols (Berry et al. 2006). Blood plasma and nasal samples were shipped to the Mycoplasma Laboratory at the University of Florida to determine the presence of antibodies to *Mycoplasma agassizii* or *M. testudineum* using enzyme-linked immunoassay (ELISA) tests (Schumacher et al. 1993; Brown et al. 1994, 2004; Wendland et al. 2007). Cultures and polymerase chain reaction tests (Brown et al. 2002) were also used. The laboratory procedures are summarized in Berry (2006).

Three primary databases were constructed for each calendar year. One database is the monthly monitoring with dates and locations in UTMs. The second database summarizes tissue samples obtained and includes data on type of samples obtained (blood plasma, plasma/lymph, and nasal lavage), date of collection, volume of samples, results of ELISA tests for *M. agassizii* and *M. testudineum*, and results of polymerase chain reaction tests for positive or suspect cultures. The first two databases are being transmitted separately to Clarence Everly, permit holder, for the federal U.S. Fish and Wildlife Service permit. They contain all Ft. Irwin-related data sets. The third database contains the data collected from health evaluations, including clinical signs of disease and trauma. This database is still in the process of receiving quality assurance and control and will be provided at a later time.

Movement Patterns

Two variables relating to movement patterns were calculated for the translocated tortoises. The first variable, dispersal distance, was calculated as the straight-line distance between the point of release and the location furthest from the release point at which the tortoise was located. The second variable, minimum total distance, was calculated as the summation of the straight-line distances between consecutive locations. Both of these measurements were calculated with straight-line distances and, as such, should be considered conservative estimates. Only live tortoises with known locations (i.e., those not dead or missing) as of December 2009 were used in these analyses (n = 68).

To determine the degree of settlement of translocated tortoises, the minimum total distance moved in 2008 was compared to that in 2009 for the 68 tortoises described above. Fidelity to cover sites was also examined (n = 68) by comparing summer (July and August) and winter (December and January) cover site locations for 2008 and 2009. The distance moved each month by these 68 tortoises was also plotted to examine seasonal and annual variation in movements patterns and differences between sexes. Finally, the number of tortoises still remaining on each plot (i.e. within the one square mile boundary of the initial release plots) was compared to the number of tortoises that have dispersed from the plot.

Data Analysis

We used repeated measures ANOVA to examine changes in weight within individual tortoises across seasons after translocation. A post hoc test was used to determine which seasons differed. Only tortoises with weight data for all four seasons (spring 2008, fall 2008, spring 2009, and fall 2009) were used in this analysis (n = 64).

One-way ANOVAs were used to compare movement variables (dispersal distance and minimum total distance) between sexes and among plots. A paired t-test was used to compare minimum total distances between 2008 and 2009. Because tortoises were released at translocation sites in March-early April 2008, we analyzed and compared movements from March-December of 2008 with movements from March-December 2009.

Fisher's exact tests were used to compare cover site fidelity between sexes, as well as death rates between translocation plots, between sexes, and between health categories (healthy, shell disease, URTD, or trauma). Fisher's exact tests were also used to compare the proportion of tortoises still remaining within plot boundaries among translocation sites and among sexes. One-way ANOVAs were used to compare the sizes (MCL) of tortoises that died to those still alive. All statistical tests were conducting using SYSTAT Software version 12.0 (SYSTAT Software Inc. 2007).

RESULTS

Summary of 2008

A total of 82 females and 76 males were translocated from the SEA to plots located in the DWMA. Of the 158 translocated tortoises, 21 females and 17 males were translocated to Plot 1.5, 21 females and 19 males were translocated to Plot 3, 19 females and 20 males were translocated to Plot 5, and 21 females and 20 males were translocated to Plot 8. As of December 2008, 43 of the initial 158 translocated tortoises were found dead (41) or salvaged for necropsy (2), and an additional 15 tortoises were unable to be located at the time and were considered missing. As of December 2008, the locations of 100 live tortoises were known. The sex ratio of these tortoises was 44 females and 56 males.

Health Evaluations

In January 2009, 44 females and 56 males were known to be alive; in December 2009, 32 females and 36 males were known to be alive. Comprehensive health evaluations were conducted on 81 translocated tortoises in the spring of 2009 (April 27 to May 4). Blood plasma and nasal lavage samples were also collected from each of these 81 tortoises. Three of these blood samples (3.7%) were a blood/lymph mixture, with at least 90% of the sample composed of blood; the remaining samples were composed of 100% blood. As of the end of spring of 2009, 55 tortoises had been found dead or salvaged for necropsy and 22 were unable to be located.

Comprehensive health evaluations were conducted on 65 translocated tortoises in the fall of 2009 (October 7 to October 27). Blood plasma and nasal lavage samples were also collected from each of these 65 tortoises. Eight of these blood samples were a blood/lymph mixture, with at least 95% of the sample composed of blood; one sample (from 4499F) was a blood/lymph mixture with 50% of the sample composed of blood; the remaining samples were composed of 100% blood. As of the fall of 2009, 69 tortoises had been found dead or salvaged for necropsy, 20 were unable to be located, and four were unable to be extracted from their cover sites for health evaluations.

Tests for Mycoplasmosis

In the spring of 2009, four (4.9%) of 81 tortoises had positive or suspect ELISA tests for *Mycoplasma agassizii* (Table 1). Three tortoises had suspect tests and one tortoise had a positive ELISA test for *M. agassizii*. Of the four tortoises with positive or suspect ELISA tests for *M. agassizii*, two were located on plot 8, one was on plot 1.5, and one was on plot 3 (Fig. 2). Additionally, two tortoises (2.5%) had positive or suspect ELISA tests for *M. testudineum*. One tortoise had a positive test and the other a suspect ELISA test for *M. testudineum*; both were located on plot 1.5 (Fig. 3). Of the 81 nasal lavage samples collected in the spring, all cultures were negative for both *M. agassizii* and *M. testudineum*.

In the fall of 2009, six (9.2%) of 65 tortoises tested for *M. agassizii* had positive or suspect ELISA tests (Table 1). Three tortoises had positive tests and three tortoises

had suspect ELISA tests for *M. agassizii*. All six tortoises were located on plots 1.5 or 8 (Fig. 4). Five of these tortoises had previous positive or suspect tests for mycoplasmosis (Table 1). All 65 tortoises tested for *M. testudineum* in the fall had negative ELISA tests (Fig. 5). Two tortoises (4024M and 4257F) which had previously tested positive and suspect, respectively, for *M. testudineum* in spring, were not available to be tested because they had been killed by predators. Results are not yet available for cultures from the 65 nasal lavage samples.

Weight

There was a significant effect of season on measured weight ($F_{3,189} = 132.0$, $p < 0.001$). The post-hoc test revealed weight was greatest in spring 2008 just after translocation, fell in fall 2008, increased back to initial levels in spring 2009, and fell again in fall 2009 (Fig. 6). Weight was not significantly different among the two spring seasons ($p = 0.964$), however it was significantly lower in fall 2009 compared to fall 2008 ($p = 0.001$).

Movements and Fidelity to Cover Sites

Summary statistics for dispersal distance and minimum total distance are reported in Table 2. The tortoise which has moved the most, 4143M translocated to plot 8, has been located on multiple dates just outside the Ft. Irwin boundary fence in the SEA, 12.6 km from its initial release location, and has moved a total distance of at least 18.8 km since its release. Overall, males have dispersed further from their release locations compared to females (means = 3256.4 m for males, 1517.9 m for females; $F_{1, 66} = 12.3$, $p = 0.001$). Males also had greater total distances moved compared to females (means = 6858.4 m for males, 3492.0 m for females; $F_{1, 66} = 23.9$, $p < 0.001$). Although the total distances that remaining live tortoises moved was greater on plots 5 (mean = 7403.3 m) and 3 (6020.8 m) compared to plots 1.5 (4899.8 m) and 8 (4778.4 m), these differences were not statistically significant ($F_{3, 64} = 1.5$, $p = 0.224$). Similarly, dispersal distance did not vary among translocations plots ($F_{3, 64} = 1.1$, $p = 0.351$).

The minimum total distance moved in 2009 (mean = 1854 m) was significantly less than that in 2008 (mean = 3222 m; $t_{67} = 4.837$, $p < 0.001$). Regarding use of cover sites, five of 68 (7.4%) tortoises have used the same cover site every season (summer and winter of 2008 and summer and winter of 2009), and an additional 36 (52.9%) tortoises have used the same cover site in at least two of these seasons. In contrast, 27 (39.7%) of 68 tortoises had minimal fidelity to sites and used a different cover site for each season examined. Females were more likely to use the same cover sites than males (Fisher's exact test, $p < 0.001$); 22 of 38 males used different cover sites for each season compared to just 5 of 30 females.

Eighteen tortoises still remain within the boundaries of their initial release plots. On plot 1.5, six tortoises still remain on the plot, compared to two on plot 3, one on plot 5, and nine on plot 8 (Table 3). However, when considering the total number of tortoises alive at each translocation site, the proportion of tortoises on plot to those off plot is not

significantly different among translocation plots (Fisher's exact test, p = 0.801). Additionally, the number of females remaining on the plots does not differ from the number of males (Fisher's exact test, p = 1.00).

There has been marked seasonal variation in movement. Tortoises moved the greatest distances in the spring months immediately following translocation (Fig. 7). Tortoises travelled large distances in the spring of 2009 and, to a lesser extent, in the fall seasons of 2008 and 2009. Tortoises were least active during summer and winter months. The distances moved in 2009 were noticeably less than those in 2008 for both the spring and fall seasons, respectively (Fig. 7). Corroborative with the previous analyses, in general males moved more than females in each month.

Mortality

As of December 2009, 70 (44.3%) of the initial 158 tortoises had been found dead (68) or had been salvaged for necropsy (2). For 2009, the death rate of the 115 remaining tortoises (27 of 115), was similar (23.5%) but slightly lower than that of 2008, the year in which tortoises were first translocated (43 of 158, 27.2%). In 2009, 24 tortoises were probably killed by coyotes or other canids, and the causes of death were unable to be conclusively determined for three tortoises (Table 4). One of these tortoises, 4644F, had been missing for six months before its remains were located. When located, the carcass was crushed, the head and limbs were still remaining and intact, and there were no obvious signs of scavenging or predation (tooth marks, gnashes, tears). A relatively well-used, Bureau of Land Management-designated dirt road was approximately 300 m from where the carcass was located. The most likely cause of death, based on the condition of remains, was crushing by a vehicle. The tortoise was probably transported to the site by a person to conceal the death. The other two tortoises, 4548F and 4441M, were found dead in the open, with no evidence of predation; the head and limbs were still intact. Both tortoises moved large distances during the summer months prior to their deaths, and the expenditures of energy may have contributed to the causes of death.

Combining data for both sexes and both years, death rates varied significantly among translocation plots (Fisher's exact test, $p < 0.001$); 12 of the tortoises that died were located on plot 1.5, 24 were located on plot 3, 26 were located on plot 5, and eight were located on plot 8. More dead tortoises were females (42) than males (28), but the difference was not statistically significant (Fisher's exact test, p = 0.126). Death rates did not differ among health categories (i.e. groups to which tortoises were assigned prior to translocation; Fisher's exact test, p = 0.7918); 21 tortoises with clinical signs of shell disease died, followed by 17 tortoises with clinical signs of trauma, 16 healthy tortoises, and 16 tortoises with clinical signs of URTD. The size of a tortoise was not related to risk of death, as the average carapace length of tortoises that died did not differ from those still alive ($F_{1,137}$ = 1.719, p = 0.192). However, tortoises that died in 2009 were larger than those that died in 2008 (mean MCL ± SE = 246.5 ± 4.7 mm vs. 231.7 ± 3.7; $F_{1,68}$ =6.05, p = 0.016). Males were driving the statistical difference between years. Males dying in 2009 were significantly larger than those dying in 2008 (MCL = 262.5 ± 7.5 mm vs. 226.3 ± 8.1 mm; $F_{1,26}$ = 10.67, p = 0.003), whereas sizes of females were not

significantly different between years (MCL = 226.5 ± 4.5 mm in 2009 vs. 234.0 ± 2.8 mm in 2008; $F_{1,40} = 1.98$, $p = 0.167$).

For data from 2009 alone, there was a significant effect of translocation plot on death rates (Fisher's exact test, $p = 0.005$; see Table 4), with again the highest rates on plots 3 and 5. Seven of the remaining 32 tortoises on plot 1.5 died in 2009, compared to six of the remaining 16 on plot 3, ten of the remaining 15 on plot 5, and four of the remaining 31 on plot 8. In 2009 alone, there was no difference in death rates among the sexes (Fisher's exact test, $p = 0.501$); 11 of the remaining 45 females died compared to 16 of the 51 remaining males.

Three of the 43 tortoises found dead in 2008 (4014F, 4720F, 4011F) previously had suspect ELISA tests for mycoplasmosis. In 2009, eleven of the 27 tortoises found dead had previous positive or suspect tests for *M. testudineum* (2533M positive in spring 2009; 4024M suspect in spring 2009; 4136F, 2023M, 2557F, 4179F, 4644F, 4085F, 4106M, 4361M, and 4442M suspect in fall 2008). Several of these tortoises had suspect ELISA tests for *M. testudineum* from fall 2008, a season with an unexpectedly high number of suspect tests for this species (Berry et al. 2009).

Of the initial 158 translocated tortoises, 20 tortoises (17.4%, 20/115) were unable to be located in December 2009 and are considered missing. Of the 20 currently missing tortoises, six had their radiotransmitters detached by a predator or otherwise, and the radiotransmitter signals of the remaining 14 are inaudible at previously known locations. As of December 2009, the locations of 68 live tortoises were known. The sex ratio of these tortoises (32 females and 36 males) is not significantly different than the sex ratio in December 2008 ($X^2 = 0.05$, df = 1, $p = 0.82$).

DISCUSSION

The results for the second year of the SEA translocation project reveal that the death rate of translocated tortoises is still high. In January 2009, 115 tortoises were known to be alive or missing. By the end of 2009, 23.5% of the tortoises had died and an additional 17.4% either remained missing or were newly missing. Overall, in December 2009, 40.9% had either been found dead or were still missing. Combining the data from 2008 and 2009, from the time of initial translocation of 158 tortoises in March-April of 2008, 70 (44.3%) tortoises have died and an additional 20 (12.7%) are missing.

As in the first year, predation by coyote continues to be the primary cause of deaths (Table 4). Overall, death rates were highest in the months immediately following translocation in 2008 and in the spring and fall of 2009 (Fig. 8). These time frames correspond to when tortoises were active and spending more time above-ground (i.e., just after translocation to a novel location, foraging in spring, and seeking mating opportunities in late summer/fall; see Fig. 7). Correspondingly, death rates were lowest in the winter of 2008 and summer of 2009 when tortoises spent more time in well-developed cover sites. While death rates were higher among females and smaller tortoises in 2008 (Berry et al. 2009), this was not the case in 2009. There is an apparent

trend that predation was initially highest among small females, but now larger males are also targets of predation (Fig. 9). This pattern may be an artifact of fewer females on the study plots after the initial wave of predation, or it may signify that coyotes have increased their abilities to successfully prey upon the larger male tortoises.

Disease may be an important factor in predation. A substantial portion of the tortoises that died in 2009 (40.7%) had previously tested positive or suspect for mycoplasmosis after being translocated. This figure includes all tortoises in the project, regardless of health group. We need to conduct further research and analysis on effects of health and disease on survival.

Between 2008 and 2009, the proportion of tortoises with suspect or positive ELISA tests increased for *M. agassizii* but decreased for *M. testudineum*. In the spring and fall of 2009, 4.9% and 9.2% of tortoises had positive or suspect ELISA tests for *M. agassizii*. These proportions of ELISA suspect and positive tortoises for *M agassizii* are higher than in 2008 (Berry et al. 2009) and higher than reported for 669 tortoises sampled in and around the SEA in 2007 (Berry and Mack 2008). Similar to findings in 2008 (Berry et al. 2009), tortoises with positive or suspect tests for *M. agassizii* are concentrated on or near plots 1.5 and 8 (Figs. 2 and 4). Three individuals had multiple positive or suspect tests for *M agassizii* during 2008 and 2009 (Table 1).

In the spring of 2009, two tortoises (2.5%) had positive or suspect ELISA tests for *M. testudineum*. These two tortoises were killed by predators during summer and thus could not be sampled in fall. All remaining tortoises had negative tests for *M. testudineum* in the fall. While the proportion of tortoises with positive or suspect tests in spring of 2008 and 2009 are similar, there is a notable discrepancy when comparing rates from the fall seasons of the same years, 31.5% in 2008 vs. 0% in 2009 (Berry et al. 2009). Shifts from positive or suspect ELISA tests for *M. testudineum* to negative status may be due to the quality of blood samples and dilution with lymph, the virulence of *Mycoplasma* spp., timing of sampling in fall, variations in the tests, or other factors.

Weight can be an important indicator of overall health (Henen et al. 1998; Christopher et al. 1999, 2003; Berry et al. 2002). Weight may reflect hydration status, expenditures of energy, availability of food and water, ability of a tortoise to find food and water, and health status. The seasonal differences in weight between spring, summer, and fall observed in the SEA tortoises are comparable to previous studies of desert tortoise populations; weight is generally higher in the spring than in fall (Christopher et al. 1999). However, the decrease in weight between the 2008 and 2009 fall seasons is of concern, and weight should continue to be monitored in conjunction with health assessments or more frequently.

The data on movement patterns of translocated tortoises will be useful for determining the appropriate size for future translocation release sites, the effects of translocation on behavior, and potentially, the effects of habitat type and quality on behavior. Our preliminary results show that translocated tortoises may disperse up to 13 km from their release location within the first two years. Therefore future managers and

scientists responsible for designing and managing translocations should consider translocation sites with a buffer zone of suitable habitat at least this large in each direction. Additionally, only 18 of the initial 158 tortoises have not dispersed from the one square mile release plots, indicating the need for translocation sites with much larger areas of quality habitat. In some regards, the translocated tortoises in this study have exhibited movement patterns similar to those reported in previous studies. Differences exist between sexes, with males moving more than females (Berry 1986, O'Connor et al. 1994), and differences exist between seasons, with higher activity levels in the spring and fall compared to the summer and winter when temperature extremes and/or lack of water limit above ground activity (see Fig. 7; Henen 1997, Henen et al. 1998, Nagy and Medica 1986). Tortoises moved less in 2009 compared to 2008, the year in which tortoises were first translocated, and some tortoises have repeatedly used the same cover sites. These results suggest that some translocated tortoises have begun to "settle" into the new sites and may be establishing home ranges, a first step in assimilating with the resident population. Also of note is that movements were greater (statistically in 2008 [Berry et al. 2009], but not for both years combined) on plots 3 and 5 compared to plots 1.5 and 8. Plots 3 and 5 also had higher death rates, and the possible relationship between increased movement and risk of mortality deserves further attention.

Continued work on this project will be directed at addressing the previously stated objectives. Health, including prevalence of mycoplasmosis and other diseases, weight, and general condition, of translocated tortoises will continue to be monitored at regular intervals by incorporating clinical signs of disease recorded during health evaluations with ELSIA test results. Signs of trauma and shell disease, along with signs of URTD, will be analyzed to determine the effects of translocation and anthropogenic impacts on these variables and whether or not incidences of disease and trauma have increased since translocation. The survival and movement patterns of translocated tortoises will continue to be monitored to assess the success of translocation. Finally, habitat characteristics, including topography, foraging and cover site availability, and levels of anthropogenic impacts, will be compared between initial capture sites and translocation release sites as well as among the four translocation plots.

RECOMMENDATIONS

1. This report does not contain a complete analysis of all health data for the translocated tortoises, between the time of translocation and December 2009, e.g., the analysis of changes in clinical signs between seasons and years. This analysis will be conducted as time permits.

2. The abnormally high death rates that began shortly after the initial translocation in March and April of 2008 have continued, and have again risen to high levels in the fall of 2009. The high death rates are primarily the result of canid (coyote) predation. The result has been loss of a significant portion of the sample population. Scientists have reported high death rates of tortoises from predators in other Ft. Irwin studies and in other research projects in California and Nevada during the last few years, and have summarized findings in a draft manuscript for the open literature (Esque et al.,

unpublished paper). Little or no action has been taken (depending on the site) by managing agencies to mitigate the impact to tortoise populations. In our study, which is in critical habitat, we designed the health and disease project to provide valuable information for recovery efforts and to mitigate some impacts of the translocation. Unfortunately, the high death rates have compromised the quality and quantity of data, as well as our ability to achieve many of the initial research objectives. Many elements of the research project will need to be repeated in future translocation efforts using a more robust sample if we are to achieve our initial goals.

3. Based on the unpublished manuscript by Esque et al. on predation, the high death rate from translocatees appears to be influenced by proximity to urban/rural areas and topographical features. There may be other local factors that contribute to elevated populations of coyotes and other predators of tortoises, including proximity to old agricultural fields, roads, trails, and recreation. The younger and smaller subadult and adult tortoises are probably more vulnerable than larger, older tortoises. We need to explore and analyze any and all factors that may affect predation of tortoises and the success of the future translocation of tortoises from the Western Expansion Area to the Western Expansion Translocation Area prior to moving tortoises.

4. Based on unexplained deaths of two tortoises during 2009 (4548F in September 2009, 4441M in August 2009), we may need to increase the health sampling of tortoises from twice per year to three or four times per year or once per season. Additional sampling may be limited to weighing the tortoises and conducting an abbreviated health evaluation (no drawing of blood or taking a nasal lavage).

5. The ELISA test for *M. testudineum* needs to be validated for *G. agassizii*. (This recommendation is repeated from Berry et al. [2009]). This research project is a very high priority, is essential to resolving questions about translocation, and should be undertaken with appropriate financial support as soon as possible. Until the test is validated, we will have continuing questions about the test and cut-off points for suspect and positive titers. We will be able to make better decisions about translocatees if the validation research has been completed.

6. Quality of Habitat (a recommendation repeated from Berry et al. [2009]). The quality of habitat where translocated tortoises were placed is a topic that needs to be addressed as soon as possible. Were the locations appropriate and if not, why not? As we can see from our data, death rates were highest on plots 3 and 5 and movements of tortoises from their original release points were highest on plot 3 and lower on plots 1.5. The soils, surficial geology, vegetative cover and composition of shrubs, elevation, and potential food sources should be evaluated retrospectively for each release site and for the original home sites as soon as possible to reveal critical factors essential to improving the chances for successful translocations. We plan to initiate such a study in 2010.

Acknowledgements. Dr. Mary Brown and Dr. Lori Wendland of the University of Florida are collaborators on this project. They provided valuable advice on interpretations and will be co-authors on any future publications for the open literature. Dr. Elliott Jacobson, also of

the University of Florida at Gainesville, is the pathologist. For tracking, monitoring, and conducting health evaluations of tortoises, we thank Marcella Waggoner, Jeremy Mack, Nate Newman, Kemp Anderson, Rafe McGuire, Sally Boisvert, Tim Hockin, Jessica Kayser, Cynthia Furman, Kevin Walsh, Tonya Rasmussen, Sara Hanner, Al DeMartini, John Boswell, Kevin Lucas, Aaron Keller, Irene Alexakos, Ben Kirkpatrick, Chris Hatton, and John Hillman, Kristina Drake coordinated fieldwork with USGS scientists at the Las Vegas Field Station. Thanks are due to K. Phillips for review and to C. Everly for advice. The National Training Center, Ft. Irwin, provided financial support.

REFERENCES

Berry, K.H. 1986. Desert Tortoise (*Gopherus agassizii*) Relocation: Implications of social behavior and movements. Herpetologica 42(1):113-125.

Berry, K.H. 2006. Progress Report for 2005. The Health Status of Resident Desert Tortoises (*Gopherus agassizii*) in the Fort Irwin Translocation Area, San Bernardino County, California. U.S. Geological Survey, Western Ecological Research Center, Moreno Valley, California. Final Report to National Training Center and Ft. Irwin, California. 15pp with appendices.

Berry, K.H. and M.M. Christopher. 2001. Guidelines for the field evaluation of desert tortoise health and disease. Journal of Wildlife Diseases 37(3): 427-450.

Berry, K.H., and J. Mack. 2008. Progress Report for 2007. The Health Status of Resident Desert Tortoises (*Gopherus agassizii*) in the Fort Irwin Translocation Area, San Bernardino County, California. U.S. Geological Survey, Western Ecological Research Center, Moreno Valley, California. Final Report to National Training Center and Ft. Irwin, California.

Berry, K.H., E. K. Spangenberg, B. L. Homer, and E.R. Jacobson. 2002. Deaths of desert tortoises following periods of drought and research manipulation. Chelonian Conservation and Biology 4:436-448.

Berry, K.H., L.D. Wendland, A. Demmon, and M.B. Brown. 2005. A comparison of lymph and plasma sample results from ELISA tests for *Mycoplasma agassizii* in desert tortoises. Presentation and Abstract from the 30th Annual Desert Tortoise Council Symposium, held in Tucson, Arizona. February 2005.

Berry, K.H., A. Demmon, T. Bailey, and J. Mack. 2006. Protocols for drawing blood from the brachial plexus and subcarapacial site of desert tortoises: Instructions for Ordering Equipment and Culture Media; Summary of How to Draw Blood and Information on How to Contract for Laboratory Analysis and Shipping Laboratory Samples. Appendix on New Technique for Conducting Nasal Lavages by L. Wendland. U.S. Geological Survey, Moreno Valley, CA. 14 p.

Berry, K.H., T.A. Gowan, and J.S. Mack. 2009. Progress Report for 2008. The health status, survival, and movements of 158 translocated Desert Tortoises (*Gopherus*

agassizii) in the Southern Expansion Area of the Fort Irwin Translocation Area, San Bernardino County, California: Year 1. U. S. Geological Survey, Moreno Valley, CA. Final Report to National Training Center and Ft. Irwin, California.

Brown, M.B., I.M. Shumacher, P.A. Klein, K. Harris, T. Correll, and E.R. Jacobson. 1994. *Mycoplasma agassizii* causes upper respiratory tract disease in the desert tortoise. Infection and Immunity 62(10):4580-4586.

Brown, M.B., K.H. Berry, I.M. Schumacher, K.A. Nagy, M.M. Christopher, and P.A. Klein. 1999. Seroepidemiology of upper respiratory tract disease in the desert tortoise in the western Mojave Desert of California. Journal of Wildlife Diseases 35(4):716-727.

Brown, D.R., I.M. Schumacher, G.S. McLaughlin, L.D. Wendland, M.B. Brown, P.A. Klein, and E. R. Jacobson. 2002. Application of diagnostic tests for mycoplasmal infections of desert and gopher tortoises, with management recommendations. Chelonian Conservation Biology 4(2):497-507.

Brown, D.R., J.L. Merritt, E. R. Jacobson, P.A. Klein, J.G. Tully, and M.B. Brown. 2004. *Mycoplasma testudineum* sp. nov., from a desert tortoise (*Gopherus agassizii*) with upper respiratory tract disease. International Journal of Systematic and Evolutionary Microbiology 45(5):1527-1529.

Christopher, M.M., K.H. Berry, I.R Wallis, K.A. Nagy, B.T. Henen, and C.C. Peterson. 1999. Reference intervals and physiologic alterations in hematologic and biochemical values of free-ranging desert tortoises in the Mojave Desert. Journal of Wildlife Diseases 35:212-238.

Christopher, M.M., K.H. Berry, B.T. Henen, and K.A. Nagy. 2003. Clinical disease and laboratory abnormalities in free-ranging desert tortoises in California (1990-1995). Journal of Wildlife Diseases 39:35-56.

Esque, T.C., K.E. Nussear, and P.A. Medica. 2005. Desert tortoise translocation plan for Fort Irwin's Land Expansion Program at the U.S. Army National Training Center (NTC) & Fort Irwin. U.S. Geological Survey, Henderson, Nevada. 24 June 2005.

Gottdenker, N.L., and E.R. Jacobson. 1995. Effect of venipuncture sites on hematologic and clinical biochemical values in desert tortoises (*Gopherus agassizii*). American Journal of Veterinary Research 56(1):19-21.

Henen, B.T. 1997. Seasonal and annual energy budgets of female desert tortoises (*Gopherus agassizii*). Ecology 78(1):283-296.

Henen, B.T., C.C. Peterson, I.R. Wallis, K.H. Berry, and K.A. Nagy. 1998. Effects of climate variation on field metabolism and water relations of desert tortoises. Oecologia 117:365-373.

Hernandez-Divers, S.M., S.J. Hernandez-Divers, and J. Wyneken. 2002. Angiographic, anatomic and clinical technique descriptions of a subcarapacial venipuncture site for chelonians. Journal of Herpetological Medicine and Surgery 12(2):32-37.

Homer, B.L., K.H. Berry M.B. Brown, G. Ellis, and E.R. Jacobson. 1998. Pathology of diseases in desert tortoises from California. Journal of Wildlife Diseases 34(3):508-523.

Jacobson, E.R., J.M. Gaskin, M.B. Brown, R.K. Harris, C.H. Gardiner, J.L. LaPointe, H.P. Adams, and C. Reggiardo. 1991. Chronic upper respiratory tract disease of free-ranging desert tortoises (*Xerobates agassizii*). Journal of Wildlife Diseases 27:296-316.

Nagy, K.A. and P.A Medica. 1986. Physiological ecology of desert tortoises in Southern Nevada. Herpetologica 42(1):73-92.

O'Connor, M.P., L.C. Zimmerman, D. E. Ruby, S.J. Bulova, and J.R. Spotila. 1994. Home range size and movements by desert tortoises, *Gopherus agassizii*, in the Eastern Mojave Desert. Herpetological Monographs 8:60-71.

Schumacher, I.M., M.B. Brown, E.R. Jacobson, B.R. Collins, and P.A. Klein. 1993. Detection of antibodies to a pathogenic mycoplasma in desert tortoises (*Gopherus agassizii*) with upper respiratory tract disease. Journal of Clinical Microbiology 31:1454-1460.

SYSTAT Software Inc. 2007. SYSTAT 12.0 Statistics. SYSTAT Software Inc., Richmond, California.

U.S. Fish and Wildlife Service. 1990. Endangered and threatened wildlife and plants; determination of threatened status for the Mojave population of the desert tortoise. Federal Register 55(63):12178-12191.

U.S. Fish and Wildlife Service. 1994. The Desert Tortoise (Mojave Population) Recovery Plan. U. S. Fish and Wildlife Service, Portland, Oregon. 73 pp and appendices.

Wendland, L., L.A. Zacher, P.A. Klein, D.R. Brown, D. Demcovitz, R. Littell, and M.B. Brown. 2007. Improved Enzyme-Linked Immunosorbent Assay to reveal *Mycoplasma agassizii* exposure: A valuable tool in the management of environmentally sensitive tortoise populations. Clinical and Vaccine Immunology 14:1190-1195.

Table 1. Previous ELISA test results for desert tortoises with positive or suspect tests in 2009. Green cells represent negative status, orange cells represent suspect, and red cells represents positive.

			M. agassizii				***M. testudineum***			
ID	**Sex**	**Plot**	**Sp08**	**Fa08**	**Sp09**	**Fa09**	**Sp08**	**Fa08**	**Sp09**	**Fa09**
4410	M	8								
2040	M	8								
4166	F	1.5								
4423	F	3								
2533	M	1.5				N/A				N/A
4024	M	1.5				N/A				N/A
4257	F	1.5								
4300	M	1.5								
4611	F	8								

Table 2. Summary statistics for movement variables of translocated desert tortoises from March 2008 through December 2009.

	Maximum (m)	Minimum (m)	Mean (m)	SD	N
Dispersal distance	12,567.3	275.2	2,438.3	2,203.6	68
Minimum total distance	18,814.4	1,070.7	5,274.2	3,280.7	68

Table 3. Counts of translocated desert tortoises that are still remaining (On Plot) or that have dispersed (Off Plot) from the boundaries of their initial release plots.

	On Plot		Off Plot		
Plot	M	F	M	F	Total
1.5	5	1	8	10	24
3	1	1	5	3	10
5	0	1	5	1	7
8	4	5	8	10	27

Table 4. Summary of translocated desert tortoises found dead in 2009.

ID	Sex	Plot	MCL	Date Located	Notes
2038	F	1.5	214	22-Sep-09	Likely predation by coyote
4136	F	1.5	201	20-Oct-09	Likely predation by coyote
4162	F	1.5	227	22-Sep-09	Likely predation by coyote
4554	F	1.5	211	4-May-09	Likely predation by canid
2533	M	1.5	260	13-Aug-09	Likely predation by coyote
4024	M	1.5	255	22-Sep-09	Likely predation by coyote
4060	M	1.5	275	22-Oct-09	Likely predation by coyote
2557	F	3	206	4-May-09	Likely predation by coyote
4179	F	3	240	24-Feb-09	Likely predation by coyote
2023	M	3	267	22-Apr-09	Likely predation by coyote
4158	M	3	266	22-Apr-09	Likely predation by coyote
4239	M	3	274	22-Apr-09	Likely predation by coyote
4640	M	3	263	4-May-09	Likely predation by coyote
2550	F	5	211	23-Sep-09	Likely predation by coyote
4288	F	5	229	18-Mar-09	Likely predation by coyote
4548	F	5	227	23-Sep-09	Cause of death unknown; no signs of predation
4556	F	5	280	21-Oct-09	Likely predation by coyote
4644	F	5	232	23-Apr-09	Crushed shell, probable vehicle kill
4073	M	5	262	14-Aug-09	Likely predation by coyote
4108	M	5	266	14-Apr-09	Likely predation by coyote
4129	M	5	284	23-Sep-09	Likely predation by coyote
4291	M	5	262	21-Oct-09	Likely predation by coyote
4442	M	5	273	08-Dec-09	Likely predation by coyote
4085	F	8	223	15-Apr-09	Likely predation by coyote
4106	M	8	265	16-Apr-09	Likely predation by coyote
4361	M	8	211	15-Apr-09	Likely predation by coyote
4441	M	8	246	18-Aug-09	Cause of death unknown; no signs of predation

Fig 1. Overview map of the Ft. Irwin Southern Expansion Area and translocation plots.

Fig 2. Results of ELISA tests for *Mycoplasma agassizii* from desert tortoises sampled in spring of 2009.

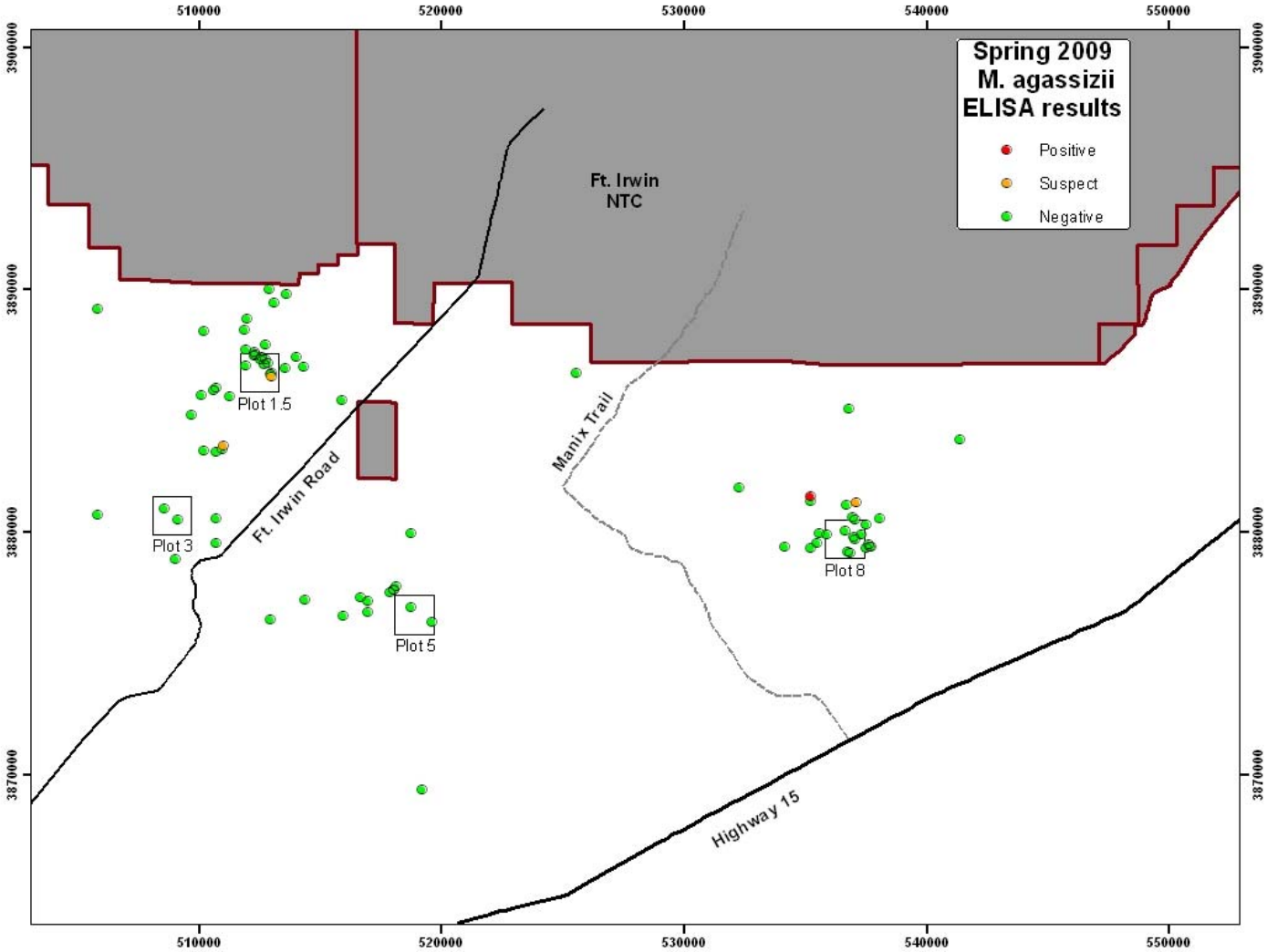


Fig 3. Results of ELISA tests for *Mycoplasma testudineum* from desert tortoises sampled in spring of 2009.

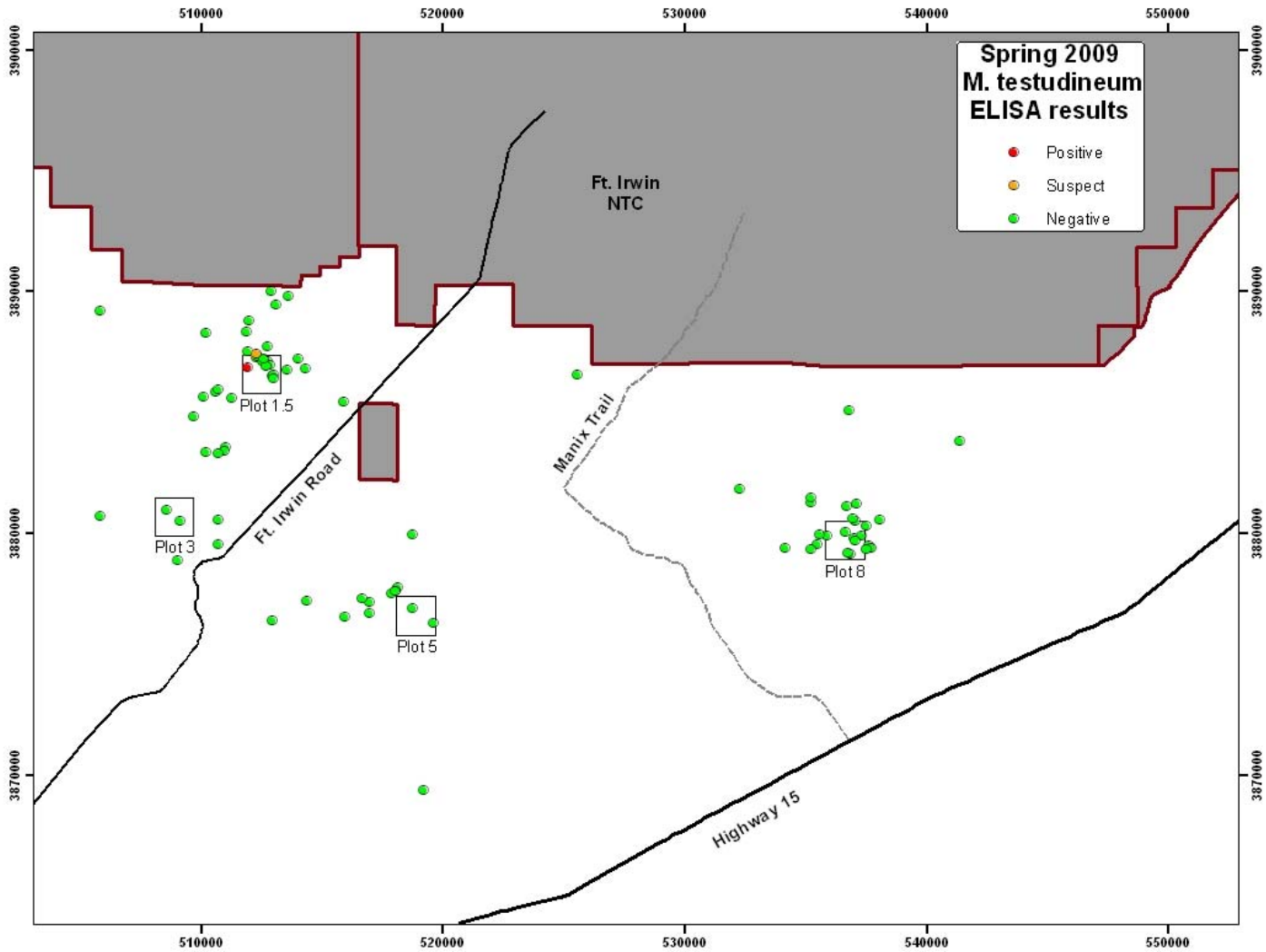


Fig 4. Results of ELISA tests for *Mycoplasma agassizii* from desert tortoises sampled in fall of 2009.

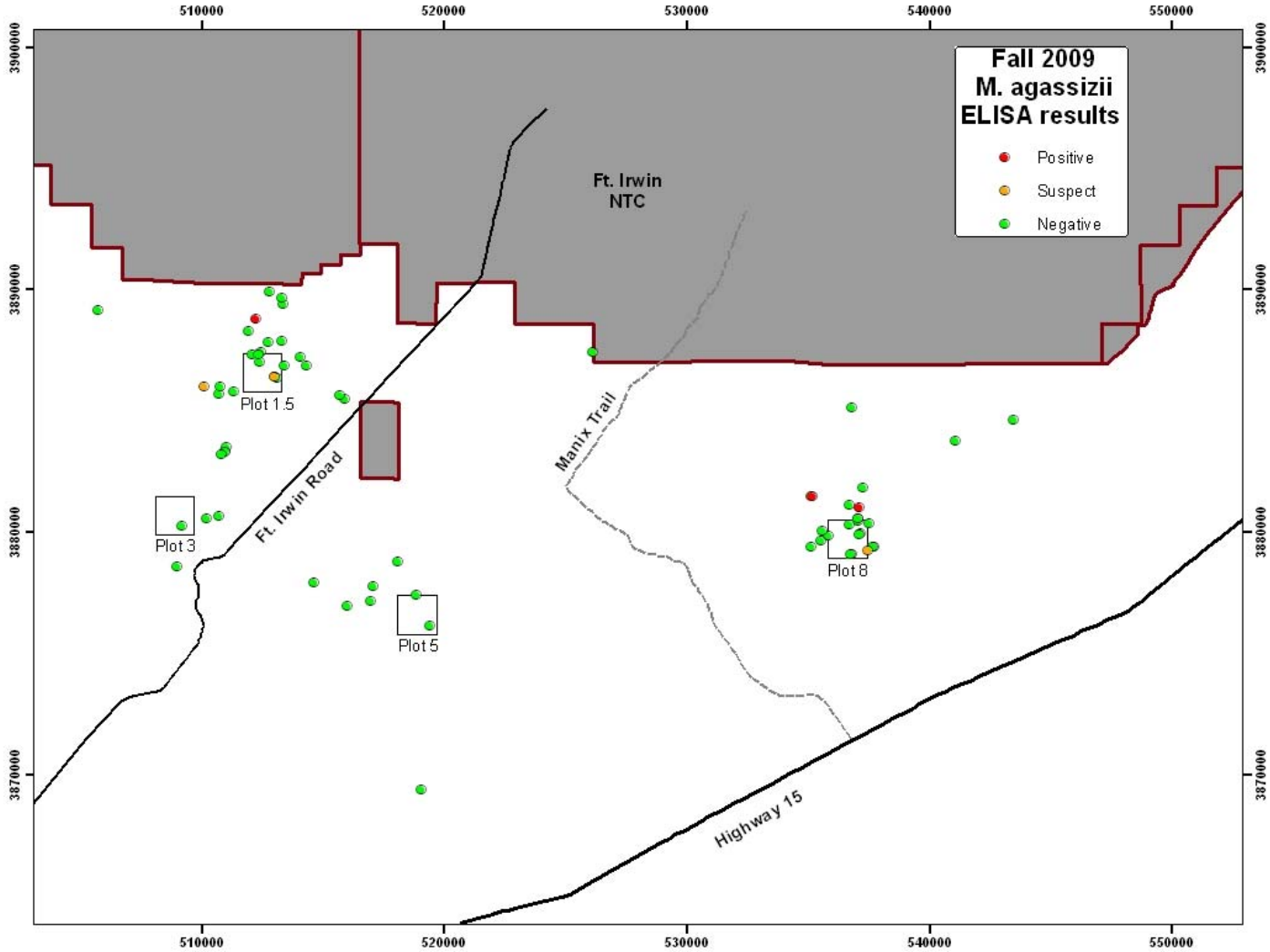


Fig 5. Results of ELISA tests for *Mycoplasma testudineum* from desert tortoises sampled in fall of 2009.

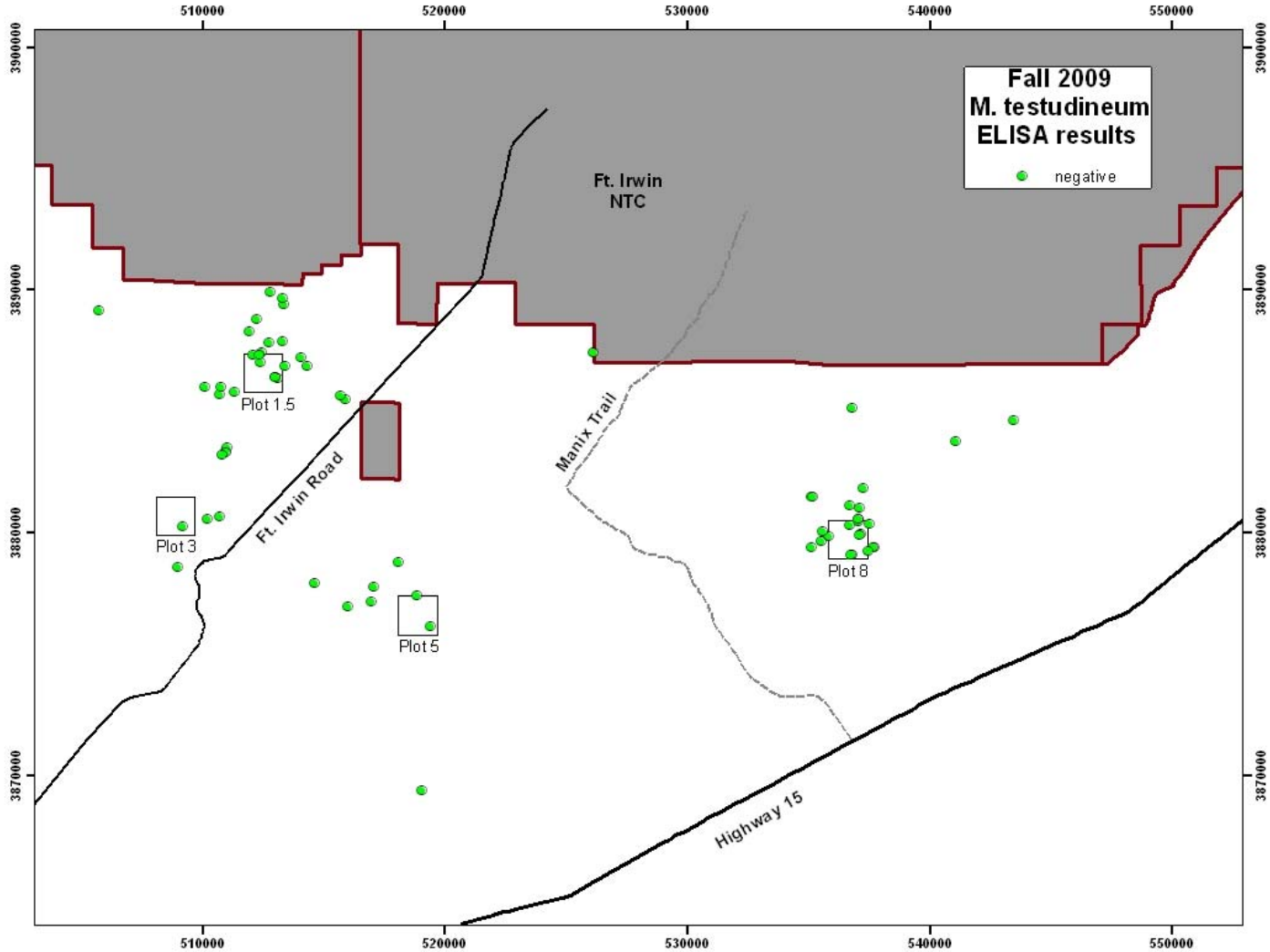


Fig 6. Mean (± SE) weight of desert tortoises (n=64) in four seasons post-translocation.

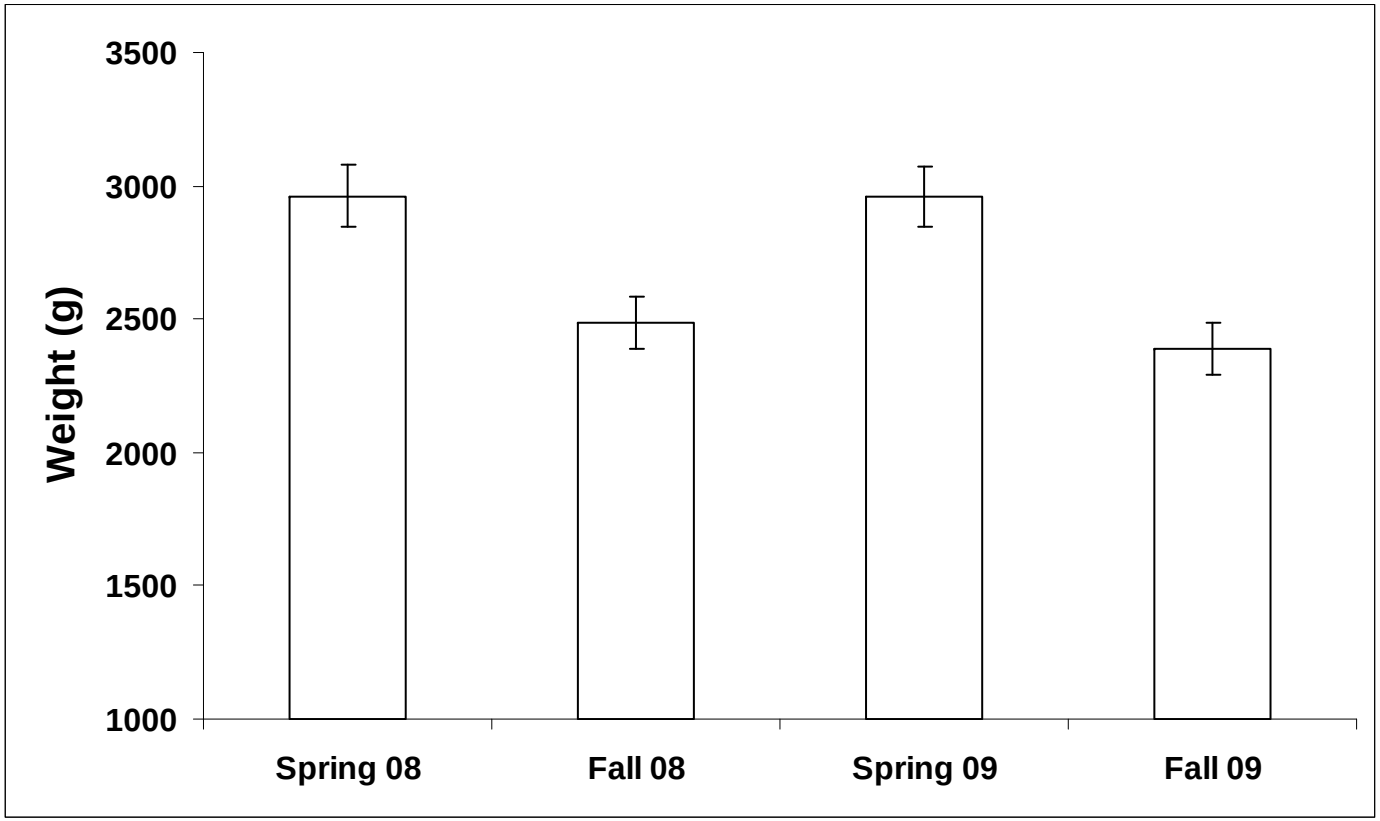


Fig 7. Mean (± SE) distances moved by desert tortoises for each month after translocation.

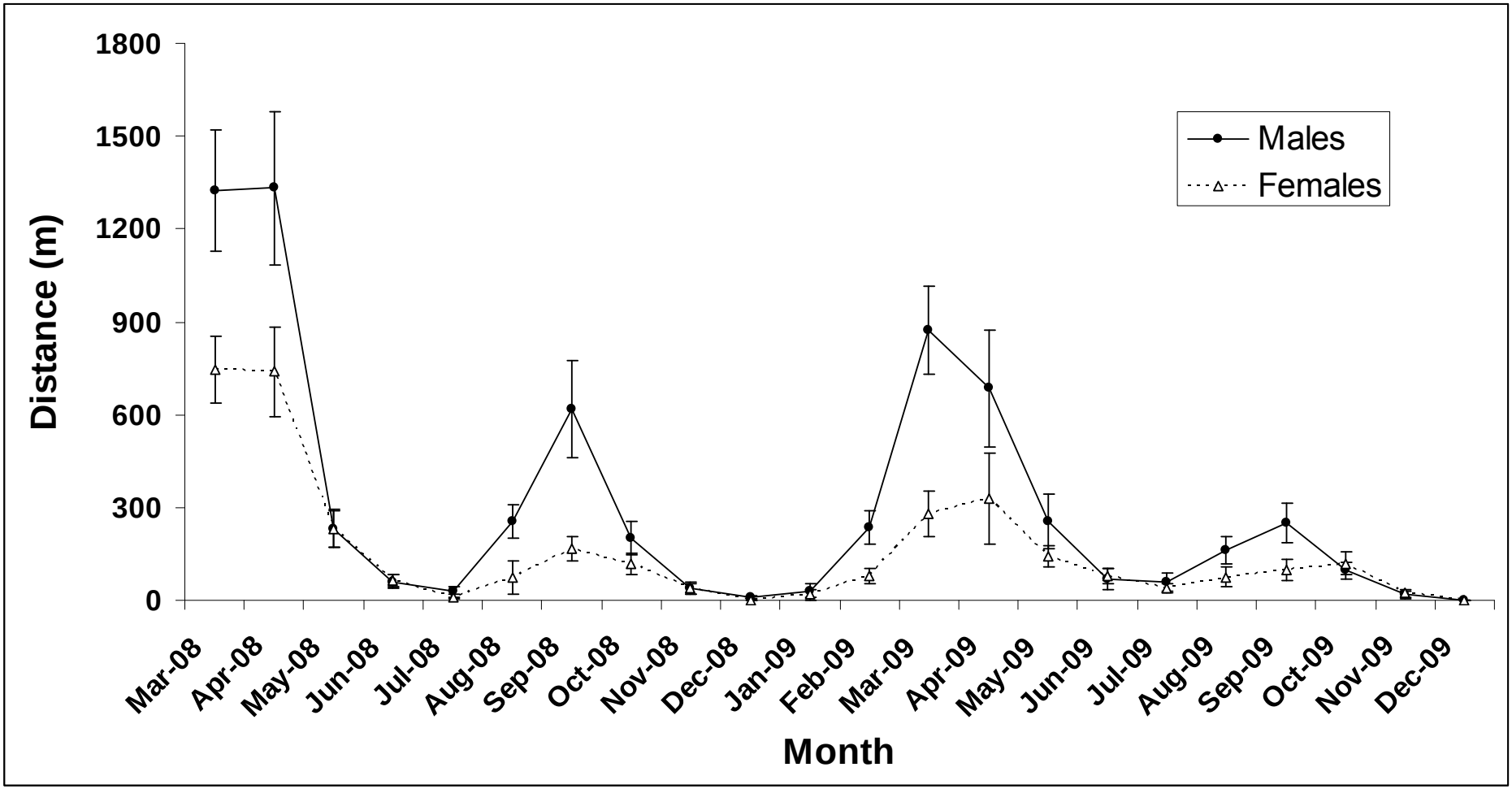


Fig 8. Percent of desert tortoises found dead (# dead/# remaining) by season for the first 20 months after translocation.

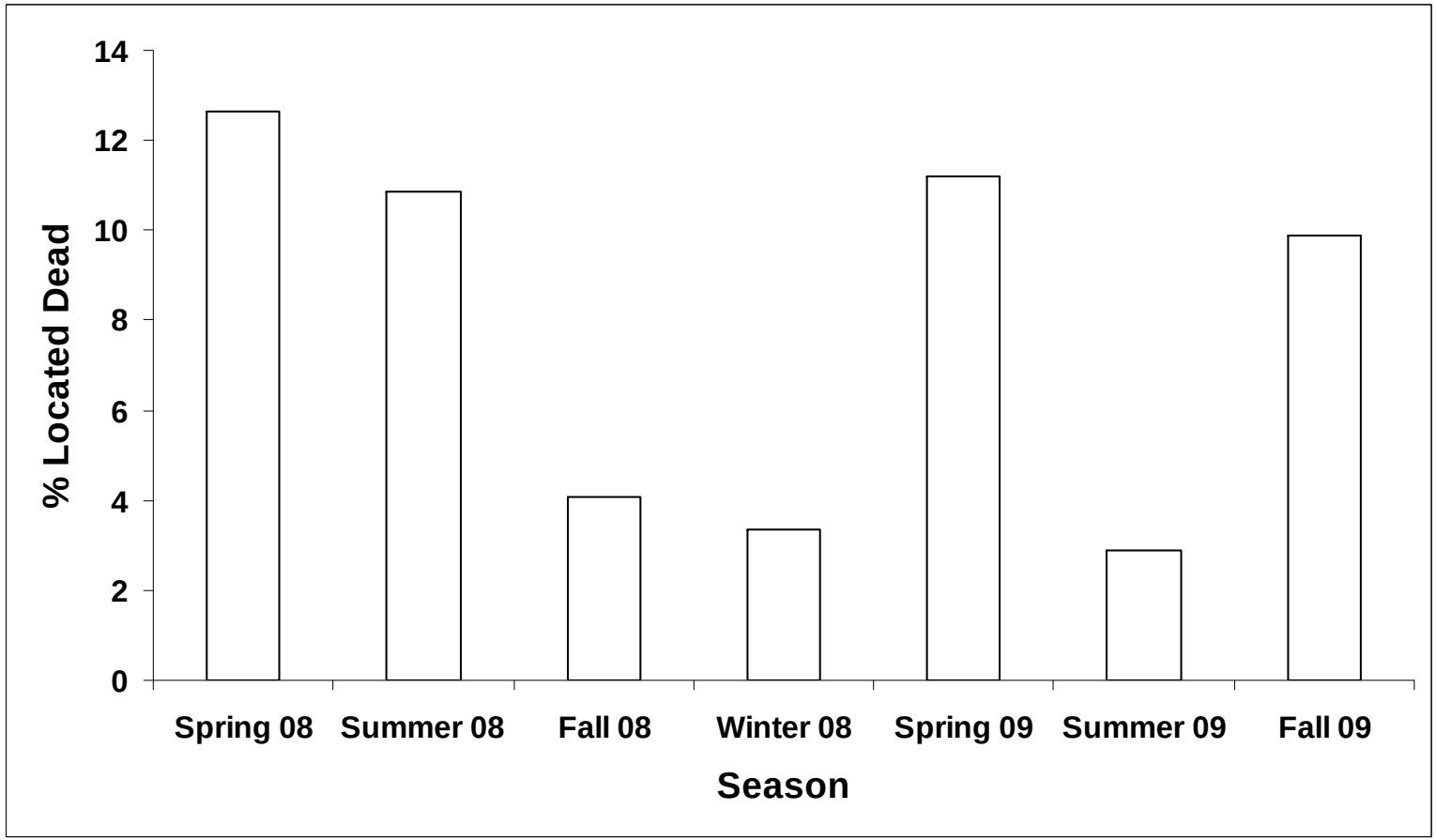
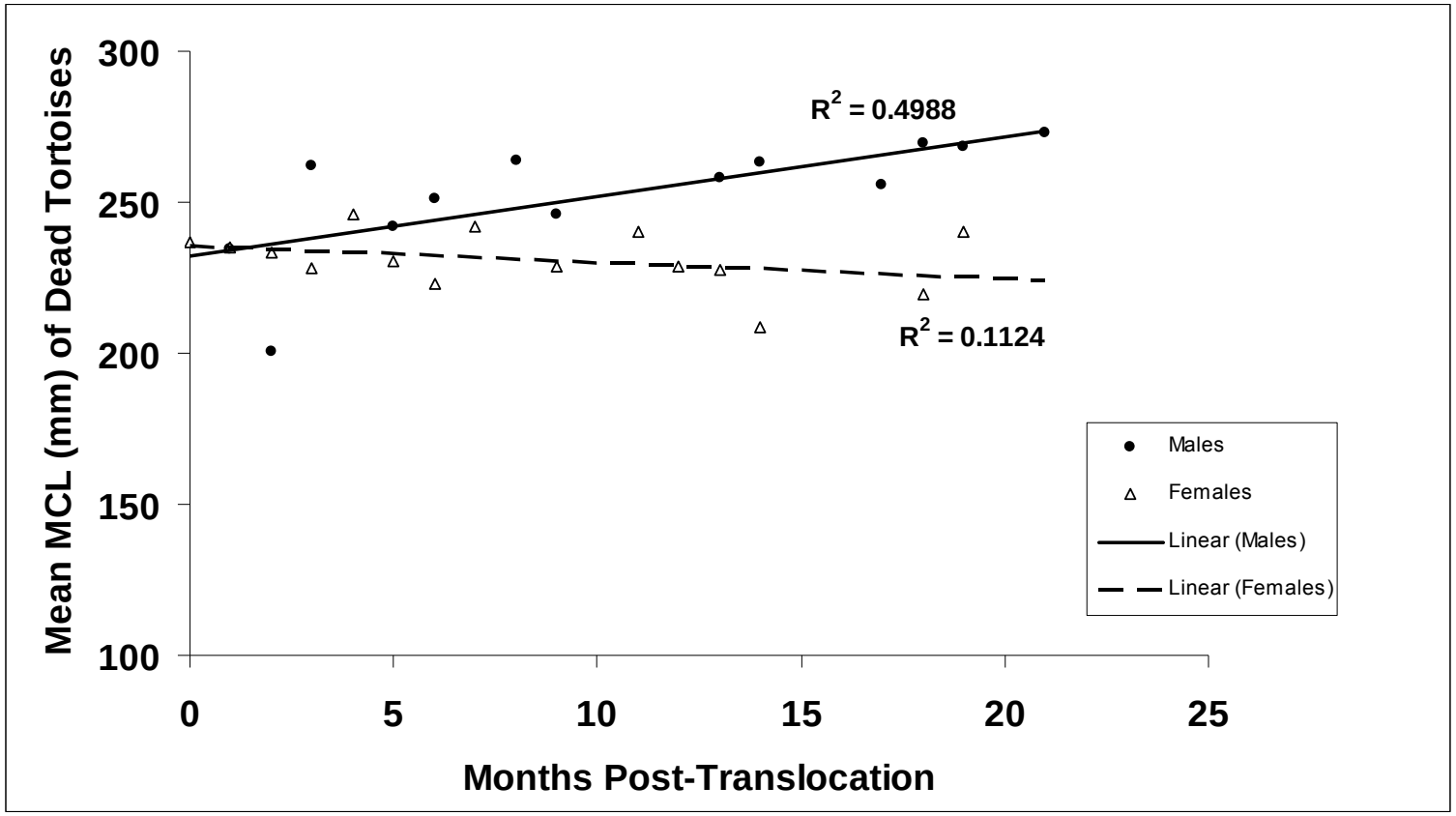


Fig 9. Mean MCL (carapace length at midline, mm) of desert tortoises located dead for each month after translocation. Note the increase in size of males found dead over time and the decrease in size of females.



Public Review Draft

Recommendations of Independent Science Advisors for The California Desert Renewable Energy Conservation Plan (DRECP)

Prepared For
Renewable Energy Action Team:

California Department of Fish & Game
U.S. Fish & Wildlife Service
U.S. Bureau of Land Management
California Energy Commission

Prepared By
The DRECP Independent Science Advisors

Public Draft

DRECP-1000-2010-008
August 2010

Produced by the **Conservation Biology Institute**. CBI is a 501(c)3 tax-exempt organization that works collaboratively to conserve biological diversity in its natural state through applied research, education, planning, and community service.

Table of Contents

1 Introduction 1
1.1 Philosophy and Approach 2
1.2 Overarching Issues and Recommendations 3
2 Plan Scope 7
2.1 Biological Goals 7
2.2 Geographic Extent of Plan Area 7
2.3 Permit Duration 12
2.4 Natural Communities 12
2.5 Covered Species 15
2.6 Additional Planning Species 30
2.7 Special Features 34
2.8 Ecological Processes 36
2.9 Environmental Gradients 40
2.10 Covered Actions 41
3 Principles for Addressing Information Gaps and Uncertainties 47
3.1 Environmental Base Maps 47
3.2 General Information Sources 50
3.3 Species Locality Data 51
3.4 Species Habitat Suitability and Distribution Models 51
3.5 Decision Support Models 54
3.6 Anticipating Climate Change 57
4 Principles for Conservation and Reserve Design 59
4.1 Review of REAT "Starting Point" Maps 59
4.2 Reserve Design Process 61
4.3 Siting, Configuring, and Mitigating Renewable Energy Developments 70
5 Additional Principles for Conserving Select Covered Species 76
6 Principles for Adaptive Management and Monitoring 78
6.1 Implement Monitoring and Adaptive Management Immediately 79
6.2 Framework and Institutional Structure 79
6.3 Hypothesis-based Monitoring and Adaptive Management 81
6.4 Monitoring Design and Research Recommendations 84
6.5 Land Management Recommendations 87
7 Literature Cited 90

APPENDICES

A Biographies of Advisors
B Draft Vegetation Alliance List for DRECP Region
C Individuals with Known Expertise Regarding Sensitive Invertebrates in the DRECP Planning Area
D CNPS List 1B & 2 Taxa in the DRECP Planning Area
E CNPS List 1B & 2 Species most likely to be affected by renewable energy projects
F Vegetation Mapping: Overview and Recommendations
G Background Documents and Maps Concerning Conservation Planning in California Deserts

Public Draft

1 Introduction

This report summarizes recommendations from a group of independent science advisors[1] for the California Desert Renewable Energy Conservation Plan (DRECP). DRECP will be a Natural Community Conservation Plan (NCCP) under California's NCCP Act of 2003. It may also serve as one or more Habitat Conservation Plans (HCP) under Section 10 of the U.S. Endangered Species Act. The NCCP Act requires input from independent scientific experts to ensure that plan decisions are informed by best available science. The advisors include experts in desert ecology, conservation biology, and other fields pertinent to informing how to conserve natural ecological communities and species in the planning region. Appendix A provides brief biographies of the advisors.

To ensure objectivity, the advisors operate independent of the plan applicants, their consultants, and other entities involved in the plan. Our recommendations are not legally binding on agencies or individuals involved in planning or implementing DRECP.

Contents of this report reflect the advisors' review of available information and maps of the DRECP process and planning area, results of a two-day science advisors' workshop, and subsequent research and discussions amongst the advisors. The science advisors met April 22-23, 2010, to hear the concerns of plan participants and begin formulating recommendations. Advisors were also encouraged to seek expert input from other scientists. We also reviewed various questions and comments submitted by agencies, stakeholders, and other interested parties before, during, and after the April 2010 science workshop (available at http://www.energy.ca.gov/33by2020/documents/). However, we made no attempt to specifically address submitted questions in a question-answer or response-to-comments format. Instead, we have attempted to address appropriate questions and comments intrinsically within our recommendations.

In general, our recommendations are organized to address four sets of principles for which the NCCP Act requires independent science input: principles for addressing data gaps and uncertainties; principles for conservation and reserve design; principles for conserving specific target species and natural communities; and principles and framework for an adaptive management and monitoring program. We also address certain aspects of the plan scope, including the geographic area, time period, species, natural communities, and actions that the plan is to cover. A previous draft of this report was circulated to other scientists for peer review, and comments received from four reviewers[2] are reflected in this draft.

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[1] Dr. Wayne Spencer, Conservation Biology Institute (Lead Advisor); Dr. Scott Abella, UNLV; Dr. Cameron Barrows, UC Riverside; Dr. Kristin Berry, USGS; Dr. Todd Esque, USGS; Kimball Garrett, Natural History Museum of LA County; Dr. Christine A. Howell, PRBO Conservation Science; Robin Kobaly, The SummertTree Institute; Dr. Reed Noss, U Central Florida; Dr.Richard Redak, UC Riverside; Dr. Robert Webb, USGS; Ted Weller, US Forest Service.

[2] Dr. Paul Beier, Northern Arizona U; Dr. James Patton, UC Berkeley (Emeritus); Dr. David Bedford, USGS; Mark Jorgensen, Anza Borrego Desert State Park (retired).

Public Draft

1.1 Philosophy and Approach

The advisors strongly agree that increasing the U.S. and California supply of renewable energy can yield numerous environmental and societal benefits, and that California's deserts have great potential for wind, solar, and geothermal energy production. However, siting and developing renewable energy developments must be done carefully, guided by best available science, to avoid undue damage to fragile desert ecosystems. Despite a widespread perception that our deserts are relatively pristine and secure, many desert species, natural communities, and ecological processes are already severely stressed by myriad human-induced changes to the landscape (Lovich and Bainbridge 1999, Berry and Murphy 2006, Bunn et al. 2007, Pavlik 2008, Webb et al. 2009a). Additional stress from direct and indirect effects of energy developments, in concert with a changing climate, portends further ecological degradation and the potential for species extinctions. Our intent is therefore to provide science-based recommendations for minimizing the adverse effects of energy developments on desert ecosystems and for contributing to the conservation and recovery of desert biota and ecosystem functions.

We understand that there are differences in the nature of impacts and mitigation actions among the various types of energy technologies, and that these technologies continue to evolve. However, we are not experts in renewable energy development, and our recommendations should be seen as one critical set of considerations for siting and designing renewable energy developments and mitigating adverse effects. We therefore have strived to allow for some flexibility in applying our recommendations.

We also understand that time is of the essence, and that fully complying with all of our recommendations prior to plan completion could cause significant delays. *This should not be used as an excuse to either ignore recommendations or to delay the plan to implement all recommendations.* We assume that in reviewing our recommendations, the planning team will determine which of them can and should be implemented immediately, and which can and should be implemented incrementally during planning, or even during plan implementation, as part of the recommended adaptive management process. For example, although we recommend a variety of field surveys and GIS-based modeling approaches to address information gaps, not all of these could feasibly be implemented in the near term, before important plan decisions must be made about siting developments or conservation actions. *We therefore strongly advocate using "no regrets" strategies in the near term—such as siting developments only in already disturbed areas—as more refined analyses become available to guide more difficult decisions.*

Finally, human understanding of desert ecosystems and species, and how they may be affected by various conservation, management, and development actions, is constantly evolving. We strongly encourage planners to recognize the dynamic nature of scientific knowledge and to seek and embrace continuous scientific input throughout the planning process and beyond. In essence, the plan should be treated as a huge environmental experiment with many uncertain outcomes. *This requires that the plan be developed and implemented incrementally in an adaptive management framework—with continuous monitoring and scientific evaluation to reduce uncertainties and improve plan actions over time.*

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1.2 Overarching Issues and Recommendations

The advisors want to emphasize several overarching concerns and recommendations that permeate the more detailed recommendations that follow:

General Assumptions and Recommendations

- *Our recommendations only apply to a plan to facilitate renewable energy developments and their appurtenant facilities, and conservation and mitigation actions for biological resources*; they do *not* apply to other sorts of development, such as urban expansion, golf courses, or biofuels production (i.e., agricultural development). Such actions could fundamentally alter our assumptions and recommendations and would therefore require additional scientific input. Our recommendations also do not address other environmental impacts of renewable energy development, such as to cultural or scenic resources.
- *Every effort should be made to avoid and minimize any new disturbance of soil surfaces in the siting, design, construction, and maintenance of any and all project features.* Arid ecosystems are strongly shaped by characteristics of soils and other geological surfaces that develop over millennia and that cannot be replicated by human actions. *Therefore, ecological impacts of projects that alter surficial geology should be presumed permanent, despite any good intentions or promises to decommission renewable energy projects at the end of their useful life and restore what came before*. This does not mean that well-conceived efforts to decommission, restore, and revegetate have no ecological value, however—only that such actions can never be assumed to replicate original nature, and therefore cannot be considered full mitigation for the original impact.
- *Obtain additional independent scientific input and review of data, models, maps, and other analytical tools and products* at important milestones during the planning process. Given the huge scope of the plan, the complexity of the issues, and the limited time we've had to research and prepare this report, we suggest that additional scientific input and review of interim products will help reduce uncertainties, avoid costly errors, build support, and increase the potential to meet DRECP goals. For example, we recommend convening independent scientists to review any environmental data layers to be used for planning or analysis (e.g., new or revised vegetation maps or species distribution maps). Scientists should also provide guidance to, and review of, any models to be used during the process, including GIS overlay models, species distribution models, population models, reserve-design algorithms, and climate change models. An important function of periodic scientific review of conservation plans is to ensure that planners followed the recommendations of earlier independent scientific input—or provide valid reasons for not having followed earlier recommendations—and to make course corrections if necessary before it is too late.

Data and Analytical Tools

- *Invest in completing a seamless, up-to-date, high-resolution, hierarchical vegetation (or landcover) map* as soon as possible to support conservation planning, renewable energy facility siting, and conservation analyses. The lack of a comprehensive and dependable land-cover base map—which is an essential data layer for spatially explicit models, maps, and analyses—is a key information gap faced by the plan. This hinders the ability to reasonably

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predict the plan's effects on target species and communities and to locate appropriate conservation and mitigation actions. The State Mapping Program (headed by Dr. Todd Keeler-Wolf, CDFG) has been mapping large areas of the state using the National Vegetation Classification System (NVCS) tailored for California, and represents the best available database. However, the program has only mapped about 60% of the Mojave Desert in California, and further progress is apparently hindered by funding constraints. This mapping effort should be funded, with *priority given to completing mapping for the rest of the DRECP planning area as soon as possible*. To allow the plan to make progress while this detailed mapping is completed (an estimated 18 months, given adequate funding), we recommend creating an "interim" or mid-level vegetation map by compiling new and existing vegetation maps, reformatting to allow for standardized representation at a mid-level hierarchy (e.g., using vegetation alliances or alliance groups), and edge-matching appropriately with adjoining states and Mexico.

- *Avoid using species observation locality data (e.g., from the California Natural Diversity Data Base, CNDDB) as a primary foundation for siting developments or conservation actions, and do not assume that absence of species observations means absence of the species*. Although CNDDB data are valuable, there are limitations to how they should be used to avoid misunderstandings. The advisors do not have faith in the interpretation of the "species sensitivity ranking" maps prepared by the Renewable Energy Action Team (REAT) that "the darker the color the higher the sensitivity." In part this is because we were not provided details concerning the ranking methods and criteria, and in part because CNDDB data were apparently the primary inputs. CNDDB data (and many other sorts of resource locality data) are presence-only data, and one cannot assume that areas lacking locality data (or "lighter in color") represent absence of species or low biological value. Moreover, CNDDB data exclude numerous available species locality data sources, do not reliably track taxa not considered rare, and generally do not differentiate among subspecies. This is important because there are many subspecies of conservation concern in the DRECP planning area that cannot be reliably located using CNDDB. Finally, for species or subspecies only recently designated as being of conservation concern, there may be few or no CNDDB entries. *CNDDB data are best used as inputs to spatially explicit distribution models (see below) or as supplements to other information sources rather than as primary predictors of species distribution and especially species absence*.

- Related to the preceding recommendation, *use appropriate, spatially explicit, dynamic, probabilistic maps and models to address information gaps* to the degree feasible. Examples include empirical (statistical) models of a species' probability of occurrence across the landscape based on survey data (e.g., Spencer et al. In Press)—or where survey data are inadequate, scientifically defensible habitat distribution models (e.g., Early et al. 2008); dynamic maps of ecological shifts expected under climate change (e.g., Stralberg et al. 2009, Wiens et al. 2009); and spatially explicit population models (e.g., Carroll et al. 2003, Carroll et al. In Press, Spencer et al. In Press) for select covered species having sufficient data (such as desert tortoise and bighorn sheep). Subject all such models to scientific peer review, sensitivity analysis, and quality assurance procedures to ensure reliability.

- *Make all analyses and decision-making processes as transparent and understandable as possible, and avoid maps that compile multiple data inputs into a single data layer without adequate documentation and justification.* For example, the advisors reviewed maps

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prepared by the REAT showing "conservation opportunity areas" that were described as supporting "key populations or connections between key populations." Compositing this information into a single map color without differentiating the various species populations or connections comprising it, and without explaining the methods used to produce the composite, made it difficult for advisors (or the public) to understand the potential value or application of these maps. Moreover, this makes it impossible to compare differing biological values or constraints on different parts of the map, which is essential to insightful prioritizing or phasing of conservation actions. Future maps should clearly differentiate, for example, existing reserve areas, unconserved areas, habitat connectivity areas, species' ranges, or other important inputs to inform decision making. If a single summary or composite map is desired for simplicity (e.g., for public outreach), the individual data layers and how they were derived and treated in the composite should still be made available, and the compositing criteria and methods clearly articulated.

- *Match the scale and resolution of each analytical task to the scale and resolution of the issues being addressed.* Some aspects of the conservation design and analysis of plan effects could be performed over the entire planning area at relatively coarse resolution—such as a "GAP analysis"[3] of existing protected areas—whereas other issues—such as how the plan may affect populations of select covered species—should be performed at finer resolution over smaller portions of the planning area to increase their sensitivity and reliability. *Do not attempt "one-size-fits-all" approaches for designing and analyzing all aspects of the plan*.
- Related to the preceding recommendation, we recommend *subdividing the planning area into ecologically relevant planning subunits* that account for heterogeneity in climate, vegetation, geology, etc., across the region. Subdivisions could be based, for example, on the Ecological Sections and Subsections delineated by the USDA and USDI (Miles et al. 1998) or the units delineated for the Mojave Desert by Webb et al. (2009a). Ecologically relevant subdivisions can help account for geographic variations in, for example, the habitat affinities and physiological tolerances of species when using habitat suitability or climate-change sensitivity models. They can also help focus mitigation measures appropriately within areas where impacts occur. It would therefore be desirable for individual planning units to contain one or more clusters of proposed renewable energy projects or zones.

Siting and Mitigation Recommendations

- To the degree possible, *site all renewable energy developments on previously disturbed land* (areas where grading, grubbing, agriculture, or other actions have substantially altered vegetation or broken the soil surface); and *site all linear facilities within or alongside existing linear rights-of-way, paved roads, canals, or other existing linear disturbances, so long as this does not create complete barriers to wildlife movements or ecological flows*. Habitat fragmentation and impediments to wildlife movements are among the greatest threats to desert communities and species, and maximizing habitat connectivity is essential to climate change adaptation. The plan should embrace a primary goal of *avoiding and minimizing any additional habitat loss or fragmentation*. "Bundling" of developments along

[3] A Gap Analysis is a quantitative, spatial assessment of how well a network of reserves protects elements of biodiversity. The "gaps" are those areas or elements not adequately represented within the reserve system.

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such features as existing roads, transmission lines, and canals will help minimize additional fragmentation impacts, although there is potential for this to increase barrier effects of existing features to wildlife movement or ecological flows. The combined effects of both new and existing (or bundled) linear features on wildlife movement should be mitigated with appropriate crossing structures or corridors to facilitate wildlife movement, coupled with appropriate fencing to minimize roadkill and funnel wildlife to crossing structures.

- *Implement and improve on conservation actions identified by existing conservation and recovery plans in the planning area*, such as the Western Mojave Desert Plan, the Northern and Eastern Mojave Desert Plan, the Northern and Eastern Colorado Desert Plan, and the Desert Tortoise Recovery Plan. Considerable scientific input has already been applied in these plans to delineate important conservation areas and design specific conservation and mitigation actions to preserve and recover sensitive desert species and communities. However, most of these conservation actions have never been fully implemented due to funding and staffing constraints at the responsible agencies (Bunn et al. 2007). *Mitigation for renewable energy developments should be used to help rectify this situation by providing funding to implement appropriate existing conservation plans and recommended recovery actions, and to improve these plans over time via the DRECP Adaptive Management and Monitoring Program*. In addition, The Nature Conservancy, SCWildlands, California Partners in Flight (CalPIF), and other conservation NGOs have been developing science-based maps and plans for conserving desert resources, and although the science advisors have not comprehensively reviewed their work or compared their approaches with our recommendations, we believe such assessments are valuable references for identifying important conservation areas and actions. To be efficient, *DRECP should use such existing conservation assessments and plans to advantage, supplementing and improving on them with peer review, as necessary, and with due consideration of our other recommendations*.
- Consider how energy developments may affect geomorphic systems and processes that sustain ecosystems and *avoid siting developments where they will disrupt essential physical geological processes*. Two important examples are eolian (wind-driven) systems such as active sand dunes, and low-slope alluvial fans that produce sheetwash that sustains downslope desert vegetation through runon. Avoid developments that might affect the production, transport, or settling of wind-blown sands or that could divert, disrupt, or channelize natural sheetflows.
- *Encourage renewable energy developments that maximize energy produced per unit land area*. Land disturbance for project footprints should be minimized to the degree feasible while maximizing energy production.
- *Encourage renewable energy developments that use less water*, such as air-cooled generators, to minimize groundwater overdraft. Groundwater flow paths should be clearly understood within the vicinity of water-cooled generation facilities to avoid impacts on groundwater-fed riparian ecosystems. *Water use from alluvial aquifers, such as those along the Mojave and Amargosa rivers, should be avoided to minimize impacts on riparian resources*.

Public Draft

2 Plan Scope

The scope of a conservation plan includes its biological goals, geographic extent, permit duration, species and communities to be addressed, and actions to be permitted.

2.1 Biological Goals

The delineation of clear objectives with measurable outcomes is central to the success of conservation planning. Objectives should guide the selection of conservation targets or goals, the structure of impact analyses, and the targets and measures selected for monitoring.

The NCCP Act (Sher 2001, California Senate Bill No. 107) states that the purpose of NCCP planning is "to sustain and restore those species and their habitat… that are necessary to maintain the continued viability of those biological communities impacted by human changes to the landscape" and that "it is the policy of the state to conserve, protect, restore, and enhance natural communities." Thus, while one objective of NCCPs and HCPs is to obtain authorizations (or permits) to "take" some habitat or individuals of listed or otherwise sensitive species, the broader goals are to sustain, restore, and enhance biological diversity and ecological functionality in general. The advisors recommend that the plan's overarching goal should be to *contribute to the persistence, distribution, and diversity of the desert biota and all its natural components and processes today and into the future, while accommodating renewable energy development and adapting to climate change*.

To create a plan that meets the goals of the NCCP Act, the advisors recommend that the plan (1) include explicit, hierarchical goals for the maintenance of biological diversity and ecosystem function in addition to goals for listed or sensitive species intended for permit coverage; (2) evaluate the impact of various planning scenarios on those biodiversity and ecosystem function goals, in addition to evaluating impacts on covered species; and (3) choose conservation strategies and policies that best satisfy this suite of biological goals while also meeting renewable energy goals.

2.2 Geographic Extent of Plan Area

The large geographic area addressed by the DRECP (Figure 1) is unprecedented for an NCCP and introduces tremendous complexity to the planning process. The plan area includes parts of the Great Basin, Mojave, and western Sonoran (or Colorado) deserts, as well as ecotones of these desert communities with the adjacent ecosystems in the Sierra Nevada, Tehachapi Mountains, Transverse Ranges (Western Transverse Ranges, San Gabriel, and San Bernardino mountains), and Peninsular Ranges (Baldwin et al. 2002). Three floristic and geographic subdivisions of California are represented: the California Floristic Province, Great Basin Province, and Desert Province. These floristic and geographic subdivisions can be further divided into regions based on climate (precipitation and temperature patterns), floristics, topography, and geology (e.g., Rowlands et al. 1982, 1995; Miles et al. 1998; Hereford et al. 2006; Webb et al. 2009a).

This large size and tremendous biogeographic and climatic diversity will make planning and analysis especially challenging. Species are naturally distributed unevenly across the landscape,

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and the spatial scale and resolution need to be fit appropriately to each organism and analysis. In some cases analyses should be done at a subregional or local scale, while other analyses may need to cover the entire planning area. For example, for some species a single habitat suitability or climate-change sensitivity model covering the entire planning area may be less accurate than several subregional models that can account for differences in how a particular species selects habitat or responds physiologically to climate variables in different geographic regions. We therefore recommend dividing the planning area into several regions or planning units that are both ecologically relevant and potentially useful for dealing with the likely clustering of renewable energy developments in different regions. Examples of appropriate subdivisions include the Ecological Sections and Subsections delineated by the USDA and USDI (Miles et al. 1998; http://www.fs.fed.us/r5/projects/ecoregions/toc.htm) or the subdivisions delineated by Webb et al. (2009a) for the Mojave Desert. Figure 2 illustrates the Ecological Subsections of the Mojave Desert as delineated by Miles et al. (1998) (similar Subsection maps exist for the Sonoran and Colorado Desert Sections in California but are not included here). Figure 3 illustrates the Subdivisions of the Mojave Desert as recognized by Webb et al. 2009a). Note that Webb et al. (2009a) only covered the Mojave Desert, so if their system is used, similar subdivisions would need to be delineated for the Sonoran and Colorado deserts to recognize such regions as the Coachella Valley, Borrego Valley-West Mesa, Imperial Valley, and East Mesa-Sand Hills.

It is evident from various maps of proposed energy developments (e.g., BLM Solar Study Areas, Commercial Renewable Energy Zones [CREZ], and solar lease applications) that the developments are likely to be clustered. This suggests that conservation planning, impact analyses, and mitigation requirements should be focused at scales and in areas relevant to the clustered footprints of these likely renewable energy areas. Subdividing should therefore also consider likely clustering patterns, such that individual planning units include one or more of these clusters. This would focus conservation and mitigation actions appropriately within the affected regions.

We understand that the planning area was expanded beyond the deserts proper to include some adjacent mountain watersheds that have high wind-energy potential. The advisors point out that this adds even more complexity to the plan by affecting a wider array of non-desert communities and species. We are also unclear why this expansion into mountainous areas of high wind potential was not done consistently along the planning boundary—in particular why the planning area ends along the eastern boundary of San Diego County rather than including areas of high wind potential in the Peninsular Ranges to the west (NREL 50-m wind resource map; http://www.windpoweringamerica.gov/maps_template.asp?stateab=ca).

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Figure 1. The DRECP Planning Area (Courtesy of CDFG).

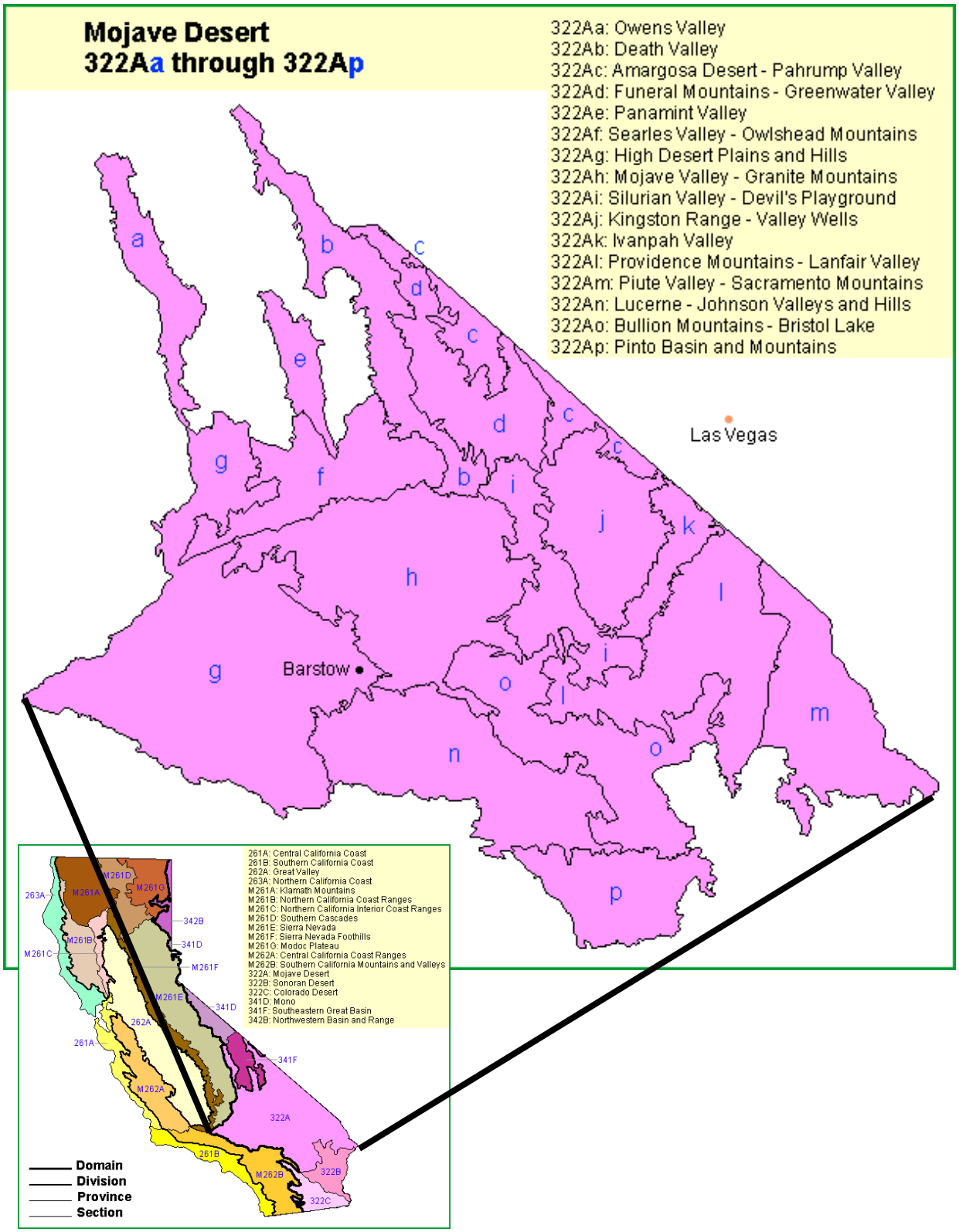

Figure 2. Ecological Subsections of the Mojave Desert Section in California as delineated by Miles et al. (1998). The inset shows Ecological Sections in California.

Figure 3. Subdivisions in the Mojave Desert delineated by Webb et al. (2009a).

2.3 Permit Duration

A permit term of 30 or 50 years is common for regional conservation plans (Rahn et al. 2006). *The advisors recommend 30 years as the maximum that is scientifically defensible in light of environmental variability, the pace of climate change, and the likely life of energy developments.* We do *not* support a longer (e.g., 50-year) duration, due to increasing uncertainties about biological effects, climate shifts, and technological changes with longer durations.

Regardless of permit duration, protections offered to biological resources (e.g., reserve areas and their management) are expected to continue in perpetuity. There should be no "walk-off" option, such that these protections are voided at the end of the permit duration. The plan should have built in requirements (such as bond funds) to ensure that remedial actions, such as decommissioning and ecological restoration, are implemented at the end of a development's useful life and that appropriate protections and management actions are continued in perpetuity. However, in recognition of the very long-term effects of surface disturbance in the desert, locations permitted for renewable energy may best be reused for similar purposes in the future (using whatever appropriate or best renewable energy technology is available at that time). If there is no need to reuse previously disturbed sites for new projects in the future, decommissioning and ecological restoration should be done using the best available and scientifically justified methods available at that time, recognizing that our current understanding of desert restoration is rudimentary. Although decommissioning and restoration may benefit DRECP species and communities, however, these future actions cannot be assumed to fully restore the original ecological conditions or full biological value of these sites, and remedial actions at the end of a project's life cannot be considered full mitigation for the project.

We also stress the importance of an effective monitoring and adaptive management program to ensure that plan goals are being met within and beyond any permit duration. Science-informed management intervention will be required to address changing conditions, including climate change, within and beyond the permit horizon. *We recommend that species statuses, species distributions, conservation needs, and other important aspects of the plan be reassessed at least every 10 years in light of changing conditions and accumulating information.*

2.4 Natural Communities

The plan should address the needs of whole, intact, natural communities and mosaics of communities at the landscape scale to accommodate natural ecological processes, including range shifts, rather than focusing just on individual species. The planning area supports hundreds of species—described, undescribed, and as of yet undiscovered—that are endemic to isolated communities or special habitat features, such as wetlands, desert wash woodlands, unique soil types, and active sand dunes. The only way to deal effectively with such species is to deal with entire communities, rather than focusing on the individual needs of every constituent species. Rare or unique desert communities and special features (such as dunes and springs), and the processes that sustain them (e.g., sand transport for dunes, groundwater aquifers for wetlands), should be "covered" by the plan in that they should be avoided to the degree possible by development and they should be foci for conservation actions. The plan should have a goal of

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no anthropogenically induced loss of the rare natural communities, special features, and ecological processes described below.

Active sand dunes provide a stark example of the high degree of endemism in isolated and unique desert communities or features. The insular distribution of desert dunes, coupled with challenging habitat conditions, has resulted in isolation, local adaptations, and speciation. The Kelso Dunes alone have 10 described endemic arthropods (eight beetles, a sand-treader cricket, and a Jerusalem cricket); the Algodones Dunes have eight (seven beetles, one sand-treader cricket); and every southern California dune system that has received any level of taxonomic surveys has one or more endemic arthropods (at least 30 or 40 overall).

2.4.1 Vegetation Alliances and Unique Plant Assemblages

We recommend using the list of California Terrestrial Natural Communities and California Vegetation Alliances included as Appendix B (provided by Dr. Todd Keeler-Wolf, California Department of Fish and Game, June 2010) to define natural communities and vegetation alliances by region. These Natural Communities and Vegetation Alliances for the state are based on Grossman et al. (1998), Holland (1986), and Sawyer et al. (2009). Over 150 vegetation alliances occur in the planning area. Those that are composed of native species, are endemic to the state, have limited distributions, and are essential to supporting covered plant and animal species should be given conservation attention.

The advisors recommend that special protective measures be taken to conserve Unique Plant Assemblages (UPAs), Stands, or Vegetation Alliances that are limited in distribution or that support sensitive or endemic species (U.S. Department of the Interior, Bureau of Land Management 1980, California Department of Fish and Game 2009). These include the following:

- Those UPAs listed and shown on maps in the California Desert Conservation Area Plan (CDCA) of 1980 as amended. The categories in the CDCA Plan should serve as a starting point and are repeated here for convenience with a few examples: Great Basin enclaves; coastal California enclaves; montane enclaves (e.g., white fir forests in Clark, New York, and Kingston mountains); enclaves of unknown affinities (e.g. Chuckwalla Bench/Chocolate Mountains Munz cholla); plant assemblages that reach their range limits within the California deserts; unusual psammophytic (sand-dependent) assemblages; plant assemblages associated with springs, seeps, and near-surface waters; plant assemblages with unusually high density or cover of some particular species (e.g., Davies Valley Succulent Scrub Assemblage); and plant assemblages with individual members of which attain great age and/or size. Two additional examples from the CDCA are listed below, the first with a new title from the list of plant alliances:
    - Spinescale Scrub Alliance, dominated by *Atriplex spinifera* [aka Mojave saltbush]
    - Crucifixion Thorn Stands (*Castela emory*), a Special Stand

- Vegetation Alliances and UPAs associated with rivers, marshes, springs, seeps, near-surface waters, washes, ephemeral standing waters (small and large playas), and ephemeral standing waters adjacent to dune systems. A few examples are:

- Desert willow woodland (*Chilopsis linearis* Alliance)
- Blue palo verde-Ironwood woodland (*Parkinsonia florida-Olneya tesota* Alliance)
- Smoke tree woodland (*Psorothamnus spinosus* Alliance)
- Fremont cottonwood forest (*Populus fremontii* Alliance)
- Arroyo willow thickets (*Salix lasiolepis* Alliance)
- Yellow willow thickets *(Salix lutea* Alliance)
- Mesquite bosque, mesquite thicket (*Prosopis glandulosa* Alliance)
- Screwbean mesquite bosques (*Prosopis pubescens* Alliance)
- Mulefat thickets (*Baccharis salicifolia* Alliance)
- Black-stem rabbitbrush scrub (*Ericameria paniculata* Alliance)
- Scale-broom scrub (*Lepidospartum squamatum* Alliance)
- Bladder sage scrub (*Salazaria mexicana* Alliance)
- Yerba mansa (*Anemopsis californica*) meadows (e.g., in Afton Canyon)
- Desert panic grass patches (*Panicum urvilleanum*) (e.g., along the Mojave River)
- California fan palm oasis (*Washingtonia filifera* Alliance)

- Vegetation Alliances associated with rare, threatened, and endangered animals, e.g.:
  - Creosote bush-white bur sage scrub (*Larrea tridentata-Ambrosia dumosa* Alliance) supporting big galleta (*Pleuraphis rigida*) or a diverse shrub layer
  - Spinescale Scrub Alliance, dominated by *Atriplex spinifera* [aka Mojave saltbush]
  - Spiny hop sage scrub (*Grayia spinosa* Alliance)

- Once wide-spread vegetation alliances, now limited and rapidly diminishing because of development, e.g.:
  - California poppy fields (*Eschscholzia californica*)
  - Joshua Tree Woodlands alliance (*Yucca brevifolia* alliance)—diminished stands in western Mojave Desert

Current scientific standards are available for classifying the uniqueness of vegetation alliances through NatureServe's Community Heritage Program, which is internationally recognized as the Natural Communities Conservation Ranking system. This system includes global uniqueness ranking (G rankings) and state (S rankings) as well as a threats ranking. It therefore provides recognition of rare and unusual plant assemblages. The ranking is categorized into five distributions. The advisors recommended that vegetation alliances occurring within the following global and state rankings be covered by DRECP:

- G1, S1 – critically imperiled; fewer than 6 viable occurrences worldwide/statewide and/or up to 518 hectares known;
- G2, S2 – imperiled; 6-20 viable occurrences worldwide/statewide and/or more than 518 – 2,950 hectares known;
- G3, S3 – vulnerable; 21-100 viable occurrences worldwide/statewide and/or more than 2,950 – 12,950 hectares known.

These rankings capture not only the rarity of the alliance within the state boundaries but also outside of the state. All of these alliance rankings are considered "rare and threatened"

Public Draft

throughout the alliance's range (Sawyer et al. 2009). High priority for conservation should be focused on those alliances and associations that have a threat ranking of 0.1 (Very Threatened) and 0.2 (Threatened). Because our knowledge of the distribution of rare and unusual vegetation alliances in the California desert is currently incomplete, it is imperative that additional vegetation mapping be completed throughout the desert regions. The advisors recommend that new data be incorporated into the database for the DRECP, and recognized and incorporated through the adaptive management strategy.

2.5 Covered Species

Typically, NCCP/HCPs identify a list of species[4] to be covered by "take authorizations" using several selection criteria, including their conservation status, occurrence in the plan area, likelihood of being affected by plan actions, and sufficiency of knowledge to determine plan effects: We agree with this general approach, but offer some further guidance concerning these selection criteria:

- **Conservation Status.** Covered species typically include those species, subspecies, or distinct population segments (hereafter, collectively called species) that are listed under state or federal Endangered Species Acts or that are considered likely to be listed during the plan's permit duration. These generally include California "Species of Special Concern" (also known as the Special Animals List) or other taxa that meet one or more criteria for listing as threatened or endangered but that have not been legally protected.
- **Occurrence in Plan Area**. Consideration should be given to all species known or likely to occur in the planning area, *during the plan's permit duration*. Note that it is quite possible that some species not currently known from the planning area could enter the planning area over the next 30 to 50 years due to climate change or other dynamics.
- **Plan Effects**. Species likely to be affected, whether positively or negatively. Often, planners only consider those species that may be adversely affected ("taken") by covered actions. However, some species may benefit from the conservation actions in the plan although they may not be adversely affected by development of renewable energy facilities.
- **Information Adequacy**. Species for which we do not have adequate information to determine how covered actions may affect them, or what conservation actions may benefit them, are often omitted from covered species lists. However, we recommend that the covered species list be kept relatively comprehensive despite such uncertainties. Data gaps that interfere with our ability to assess plan effects can be reduced over time via the adaptive management and monitoring program, ecological research, and advances in predictive modeling (e.g., for species' distributions and responses to plan actions or climate change). However, if little-known species are left off the covered species list due to information gaps, they are less likely to garner the research and monitoring attention needed to close those gaps and ensure their conservation.

[4] Note that under the Endangered Species Act, species, subspecies, or distinct population segments can be listed as threatened or endangered. Distinct population segments are populations of a species that are distinct, relatively reproductively isolated from other populations of the species, and represent a significant evolutionary lineage of the species. Throughout this document, we use the word species to refer to all three categories (species, subspecies, or distinct population segment).

Public Draft

The advisors reviewed a preliminary list of species of "planning interest" included in Exhibit B of the DRECP Planning Agreement (dated March 2010; Table 1). We noted a variety of errors, including inappropriate inclusion of full species rather than subspecies of conservation concern, inclusion of species not found in the planning area, exclusion of species or subspecies of conservation concern that do occur in the plan area, and apparently a lack of consideration of information from previous conservation and recovery plans. The following sections address these issues in more detail by major taxonomic groupings. They provide *examples* of apparent errors of omission and commission in the current species list and recommendations for assembling a more defensible covered species list. *We recommend that DRECP form a committee or subcommittee of qualified biologists to prepare a proposed covered species list based on the factors described above, and considering information presented in this section.*

We also recommend that any *future lists of species produced for DRECP be organized in traditional taxonomic order using scientific nomenclature*. The current list included as Table 1 is organized alphabetically by common name, with no regard for taxonomic hierarchy or species relations. Some species and subspecies of conservation concern in the planning area do not have common names and can only be identified by scientific name. Because there is no standardized list of common names for most taxa (with the exception of North American birds, for which the American Ornithologists Union establishes standardized list) multiple species may share the same common name, or the same species may have multiple names. Scientific nomenclature exists to avoid such confusion.

Table 1. "Preliminary list of species of planning interest" included as Exhibit B of the DRECP Planning Agreement (March 2010). *This is **not** included here as a recommended covered species list because it contains errors and requires substantial revision (see text).*

Common Name	Scientific Name	CESA	ESA	California Special Concern	BLM Sensitive
ANIMALS					
Arizona myotis	*Myotis occultus*			X	
Arroyo toad	*Anaxyrus californicus*		Endangered		
Arroyo toad	*Bufo californicus*			X	
Bald eagle	*Haliaeetus leucocephalus*	Endangered	Delisted		
Barefoot gecko	*Coleonyx switaki*	Threatened			
Bendire's thrasher	*Toxostoma bendirei*				X
Bewick's wren	*Thryomanes bewickii*			X	
Big free-tailed bat	*Nyctinomops macrotis*			X	
Bighorn sheep	*Ovis canadensis*	Threatened	Endangered		
Burrowing owl	*Athene cunicularia*			X	X
Cactus wren	*Campylorhynchus brunneicapillus*			X	
California black rail	*Laterallus jamaicensis coturniculus*	Threatened			
California condor	*Gymnogyps californianus*	Endangered	Endangered		
California leaf-nosed bat	*Macrotus californicus*			X	X

Common Name	Scientific Name	CESA	ESA	California Special Concern	BLM Sensitive
California pocket mouse	*Chaetodipus californicus*			X	
Cave myotis	*Myotis velifer*			X	X
Coachella Valley fringe-toed lizard	*Uma inornata*	Endangered	Threatened		
Coachwhip	*Masticophis flagellum*			X	
Colorado desert fringe-toed lizard	*Uma notata*			X	X
Common ensatina	*Ensatina eschscholtzii*			X	X
Common yellowthroat	*Geothlypis trichas*			X	
Crissal thrasher	*Toxostoma crissale*			X	
Desert night lizard	*Xantusia vigilis*			X	
Desert tortoise	*Gopherus agassizii*	Threatened	Threatened		
Desert woodrat	*Neotoma lepida*			X	
Ferruginous hawk	*Buteo regalis*				X
Flat-tail horned lizard	*Phrynosoma mcallii*			X	X
Fringed myotis	*Myotis thysanodes*				X
Gila monster	*Heloderma suspectum*			X	X
Gila woodpecker	*Melanerpes uropygialis*	Endangered			
Gilded flicker	*Colaptes chrysoides*	Endangered			
Golden eagle	*Aquila chrysaetos*				X
Gray vireo	*Vireo vicinior*			X	X
Inyo Mountains salamander	*Batrachoseps campi*			X	X
Least Bell's vireo	*Vireo bellii pusillus*	Endangered	Endangered		
Le Conte's thrasher	*Toxostoma lecontei*			X	
Little pocket mouse	*Perognathus longimembris*			X	X
Loggerhead shrike	*Lanius ludovicianus*			X	
Long-eared myotis	*Myotis evotis*				X
Long-eared owl	*Asio otus*			X	
Lucy's warbler	*Vermivora luciae*			X	
Merriam's kangaroo rat	*Dipodomys merriami*			X	
Mojave fringe-toed lizard	*Uma scoparia*			X	X
Mountain plover	*Charadrius montanus*			X	
Nelson's antelope squirrel	*Ammospermophilus nelsoni*	Threatened			
Orange-throated whiptail	*Aspidoscelis hyperytha*			X	
Pallid bat	*Antrozous pallidus*			X	X
Palm Springs round-tailed ground squirrel	*Spermophilus tereticaudus chlorus*		Candidate		
Panamint alligator lizard	*Elgaria panamintina*			X	X
Pocketed free-tailed bat	*Nyctinomops femorosaccus*			X	
Quino checkerspot butterfly	*Euphydryas editha quino*		Endangered		
Rosy boa	*Charina trivirgata*				X
Round-tailed ground squirrel	*Spermophilus tereticaudus*			X	
Rufous-crowned sparrow	*Aimophila ruficeps*			X	

Public Draft

Common Name	Scientific Name	CESA	ESA	California Special Concern	BLM Sensitive
Sage sparrow	*Amphispiza belli*			X	
Snowy plover	*Charadrius alexandrinus*		Threatened	X	
Southern rubber boa	*Charina umbratica*			X	
Spotted bat	*Euderma maculatum*			X	X
Summer tanager	*Piranga rubra*			X	
Swainson's hawk	*Buteo swainsoni*	Threatened			
Tehachapi slender salamander	*Batrachoseps stebbinsi*	Threatened			
Townsend's big-eared bat	*Corynorhinus townsendii*			X	
Vermilion flycatcher	*Pyrocephalus rubinus*			X	
Western mastiff bat	*Eumops perotis*			X	X
Western patchnose snake	*Salvadora hexalepis*			X	
Western pond turtle	*Actinemys marmorata*			X	X
Western red bat	*Lasiurus blossevillii*			X	
Western skink	*Eumeces skiltonianus*			X	X
Western small-footed myotis	*Myotis ciliolabrum*				X
Western yellow-billed cuckoo	*Coccyzus americanus occidentalis*	Endangered	Candidate		
Willow flycatcher	*Empidonax traillii*	Endangered			
Yellow warbler	*Dendroica petechia*			X	
Yellow-breasted chat	*Icteria virens*			X	
Yuma clapper rail	*Rallus longirostris yumanensis*	Threatened	Endangered		
Yuma myotis	*Myotis yumanensis*				X
PLANTS					
Bird-foot checkerbloom	*Sidalcea pedata*	Endangered	Endangered		
Coachella Valley milk-vetch	*Astragalus lentiginosus* var. *coachellae*		Endangered		
Cushenbury buckwheat	*Eriogonum ovalifolium* var. *vineum*		Endangered		
Cushenbury milk-vetch	*Astragalus albens*		Endangered		
Cushenbury oxytheca	*Acanthoscyphus parishii var. goodmaniana*		Endangered		
Cuyamaca larkspur	*Delphinium hesperium* ssp. *cuyamacae*	Rare			
Lane Mountain milk-vetch	*Astragalus jaegerianus*		Endangered		
Mojave tarplant	*Deinandra mohavensis*	Endangered			
Owens Valley checkerbloom	*Sidalcea covillei*	Endangered			
Red Rock tarplant	*Deinandra arida*	Rare			
Santa Ana River woollystar	*Eriastrum densifolium* ssp. *sanctorum*	Endangered	Endangered		
Slender-petaled thelypodiu	*Thelypodium stenopetalum*	Endangered	Endangered		
Southern mountain buckwheat	*Eriogonum kennedyi* var. *austromontanum*		Threatened		
Triple-ribbed milk-vetch	*Astragalus tricarinatus*		Endangered		

Public Draft

2.5.1 Mammals

Table 1 contains significant errors of omission and commission concerning potential covered mammal species. A number of mammal taxa were included in Table 1 on the basis that they are California Mammal Species of Special Concern (MSSC), but without appropriate recognition of subspecific designations and ranges. Note that the MSSC list is currently being revised by a team of mammalogists that are reviewing all available data on the status and distribution of mammals in California (W. Spencer, S. Osborn, et al., In Prep.). The MSSC team has compiled a large database of mammal locality data and is preparing range maps and other information for peer review. A final MSSC list and assessment document is scheduled for completion by May 2011. We recommend finalizing the list of potential covered mammals in late 2010, by which time the draft list of MSSC, along with refined range maps, should be available.

In the meantime, the following species could be ***removed*** from the potential covered species list due to relatively low level of conservation concern within the planning area, or lack of occurrence in the planning area:

- **California pocket mouse** (*Chaetodipus californicus*). This species of pocket mouse is widespread and common in California, mostly in shrublands outside of desert regions. Although one subspecies, *C.c. femoralis*, is a current California MSSC, it is associated with coastal sage scrub outside the current planning area boundaries.
- **Desert woodrat** (*Neotoma lepida*). This is a very common and widespread species throughout California's desert regions. Although one subspecies (*N.l. intermedia*) is a current MSSC, it is associated with coastal sage scrub outside the current planning area boundaries. Moreover, the taxonomy of the *Neotoma lepida* group was recently revised by Patton et al. (2007), which removed a number of former *N. lepida* subspecies, subsuming some within other species of *Neotoma*, including *N.l. intermedia*, which is now *N. bryanti intermedia*. The status of all species and subspecies in the revised taxonomy is currently under review, but at this point it seems unlikely that any *Neotoma* species or subspecies in the DRECP study area will be considered to be of conservation concern.
- **Merriam's kangaroo rat** (*Dipodomys merriami*). This smallest of the kangaroo rat species is common and widespread throughout the deserts, and it is not of conservation concern throughout most of its range. One subspecies of *D. merriami* is federally Endangered (the San Bernardino kangaroo rat, *D.m. parvus*), but it occurs outside the DRECP area, west of the San Bernardino and San Jacinto Mountains. Similarly, another highly restricted and impacted subspecies (the earthquake kangaroo rat, *D. m collinus*) occurs outside the DRECP area in sandy upland valleys in the Peninsular ranges in San Diego County and southernmost Riverside County. Finally, although *D.m. arenivagus* has a highly restricted range that is partially within the plan area, west of the Salton Sea, it is not currently an MSSC and does not appear likely to be added to the MSSC list.
- **Nelson's antelope squirrel** (*Ammospermophilus nelson*i). This state Threatened species of ground squirrel is found in the San Joaquin Valley, outside the DRECP plan area.
- **Yuma myotis** (*Myotis yumanensis*). Although considered sensitive by the BLM, the Yuma myotis is widely distributed, roosts in a wide variety of natural and anthropogenic structures, and appears well adapted to survival in close proximity to humans. It is considered low-

Public Draft

medium priority for conservation by the Western Bat Working Group. Its potential for listing over the next 30-50 years is minimal.

The following species can be ***retained*** on the potential covered species list for DRECP even though, *at the full species level*, they are quite common and widespread. Nevertheless, *several rare or narrowly distributed subspecies of these species are of conservation concern in the planning area*. *We recommend considering each subspecies individually for inclusion or exclusion from the covered species list*, as detailed here:

- **Little pocket mouse** (*Perognathus longimembris*). This small, silky pocket mouse is associated with fine sandy soils throughout California's deserts and some southern California cismontane (west of the coastal mountains) basins and coastal plains. Although the species as a whole is quite common and widespread, it has a number of rare, endemic subspecies that are of conservation concern, *each of which should be treated separately as a covered species*:
  - ***P.l. bangsi*** (Palm Springs pocket mouse) is restricted to fine sandy soils in the Coachella Valley and southern portions of Joshua Tree National Park, south along either side of the Imperial Valley to about the Mexican border (Ocotillo). It is a current MSSC and will likely remain on the MSSC list due to its highly restricted range and loss of most of its habitat on the Coachella and Imperial Valley floors (Brylski et al. 1998).
  - ***P.l. bombycinus*** (no common name) ranges from Baja California, Mexico, into the southern and eastern Colorado Desert in California (Brylski et al. 1998). It is a current MSSC that is likely to remain on the list due to restricted distribution and habitat loss.
  - ***P.l. brevinasus*** (Los Angeles pocket mouse) is restricted primarily to cismontane basins outside the DRECP plan area; accept where it intergrades with *P.l. bangsi* in the San Gorgonio Pass-Palm Springs area (Brylski et al. 1998). It is a current MSSC and will likely remain on the list due to its highly restricted distribution and loss and fragmentation of populations by urban development.
  - ***P.l. internationalis*** (Jacumba pocket mouse) is found southwest of the Salton Sea and into Baja California, Mexico. Due to restricted range, there is some potential it will become an MSSC, but it is unclear whether it occurs within current DRECP boundaries.
  - ***P.l. salinensis*** (no common name) is known only from within Death Valley National Park, so it is unlikely to be affected by plan actions (J. Patton, personal communication).
  - ***P.l. tularensis*** (no common name) is restricted to the Kern Plateau, probably outside of DRECP boundaries (J. Patton, personal communication).
- **Round-tailed ground squirrel** (*Spermophilus* [now *Xerospermophilus*] *tereticaudus*)[5]. This species is fairly common and widespread in the Colorado and Mojave Deserts south and east of the Mojave River. At the full-species level, it is not of elevated conservation concern.

[5] A common issue with CNDDB and California's Species of Special Concern lists is that they do not keep up with taxonomic changes. For example, the genus *Spermophilus* was recently split into eight genera based on substantial morphological, genetic, ecological, and behavioral variation (Helgen et al. 2009). Although in this particular case, the change did not affect the conservation status of the taxa in DRECP, in other cases it does, and these differences cannot be ascertained from CNDDB or CWHR data and range maps.

Public Draft

However, the subspecies *S.t. chlorus* (Palm Springs ground squirrel) has a very limited distribution in the Coachella Valley, where much of its sandy habitat has been lost to development. The Palm Springs ground squirrel is an MSSC and a federal Candidate for listing, and is highly likely to remain an MSSC with potential to become listed as Threatened or Endangered. *We therefore recommend retaining X.t. chlorus, but* ***not*** *the full species of X. tereticaudus, as a candidate for coverage under DRECP*.

The following species should be ***added*** as potential covered species because they are found in the planning area, are of conservation concern, and could be affected by the plan:

- **Tehachapi pocket mouse** (*Perognathus alticolus inexpectatus*). This MSSC is restricted to a narrow range along the western-most edges of the Mojave Desert and adjacent slopes of the Tehachapi and San Gabriel Mountains. It has only been detected from the vicinity of Tehachapi Pass, west to Mount Pinos, and south to Elizabeth and Quail Lakes, between 1030 and 1830 m elevation. This range corresponds closely with areas of high wind energy potential (NREL wind potential maps).
- **Yellow-eared pocket mouse** (*Perognathus parvus xanthonotus*). Although not currently on the MSSC list[6], this narrow-endemic pocket mouse is BLM sensitive and likely to be added to the MSSC list. It is known from only four localities on the eastern slope of the Tehachapi Mountains at Horse, Sage, Freeman, and Indian Wells canyons, between 1400 and 1615 m elevation. This range coincides with an area of high wind-energy potential.
- **Mohave ground squirrel** (*Spermophilus [Xerospermophilus] mohavensis*). This state-listed Threatened species was clearly an inadvertent omission from the preliminary list of species (Table 1), as it is a key species of concern in areas with high solar development potential in the western Mojave Desert.
- **Mojave River vole** (*Microtus californicus mohavensis*). This subspecies of the California vole is an MSSC. It is restricted to areas along the margins of the Mojave River where water comes to the surface due to shallow water table, in and near Victorville and Oro Grande. Although it is unlikely to be directly impacted by energy developments, any actions that might affect the hydrology of the Mojave River would be detrimental. A *Mictrotus californicus* population also occurs at Harper Lake Marsh about 10-15 miles northwest of Barstow. Although it is unknown whether this is *M.c. mohavensis* or another, less sensitive subspecies, any populations of voles or other species restricted to isolated wetland habitats in the desert may be unique and should be considered sensitive. The advisors recommend avoiding developments that could reduce the water table at Harper Lake or any other desert wetlands.
- **Amargosa River vole** (*Microtus californicus scirpensis*). This subspecies of the California vole is both federally and state-listed as Endangered. It is associated with Olney bulrush (*Scirpus olneyi*) marshes along the Amargosa River, and is found in disjunct populations that may be temporary in nature (Bleich 1998). Although this species is unlikely to be directly

[6] Although Williams (1986) originally included yellow-eared pocket mouse as an MSSC, Brylski et al. (1998) placed it on an MSSC "Watch List" due to lack of sufficient information.

Public Draft

impacted by energy developments, any actions that may affect hydrology of the Amargosa River would be detrimental.

- **Hoary bat** (*Lasiurus cinereus*). Although this species is widely distributed and unlikely to be listed as threatened or endangered in the near future, hoary bats are the most frequently killed species at wind energy developments in North America (Arnett et al. 2008) and have been recorded as fatalities at wind energy facilities within the DRECP (Chatfield et al. 2009). Given the cumulative impacts of massive expansion of utility-scale wind energy development in the United States, combined with low reproductive rates of bats, there is some potential for hoary bats to be added to one or more special status lists within the next 30-50 years.
- **Western yellow bat** (*Lasiurus xanthinus*). This species is currently on the MSSC list and a large proportion of its distribution in California is within the DRECP area. Fatalities of this species have been recorded within the DRECP area (Chatfield et al. 2009).

2.5.2 Birds

The Draft Covered Species List (Table 1) requires modification to reflect the latest listings by the California Department of Fish and Game and the United States Department of Interior, as well as to apply more accurately to relevant subspecies and other infraspecific categories. In many cases the California Bird Species of Special Concern list (hereafter BSSC; Shuford and Gardali 2008) limits the seasonal or infraspecific application of its listings. United States Fish and Wildlife Service (USFWS) listings also need to be updated, resulting in some additions to the covered species list (see below).

Subspecies taxonomy is in a state of flux for North American birds. The most recent formal treatment of subspecies by the American Ornithologists' Union Committee on Classification and Nomenclature was published in 1957 (AOU 1957); more recent formal checklists (e.g., AOU 1998) do not include subspecies, although well-marked infraspecific groups may be annotated. Current trends recognize the utility and convenience of subspecies (Fitzpatrick 2010) and the need for more quantitative diagnoses of subspecies (e.g. Remsen 2010). Without refinement of subspecies treatments, conservation efforts can be confused or even hampered (Haig and D'Elia 2010).

We recommend that the following species be ***removed*** from the list of potentially covered species:

- **Bewick's wren** (*Thryomanes bewickii*). No mainland subspecies in western North America have formal conservation status. The widespread cismontane subspecies *charienturus* occurs in the western margins of the Mojave and Colorado deserts, and the Great Basin subspecies *eremophilus* occurs in the higher elevations of the northeastern Mojave Desert; there are no indications of declines of either taxon on the California deserts.
- **Cactus wren** (*Campylorhynchus brunneicapillus*). Although this species needs to be considered in desert conservation planning, populations in the DRECP area have no formal conservation status. The California BSSC designation applies only to the coastal subspecies *sandiegensis* from southern Orange County through coastal San Diego County (Shuford and Gardali 2008), though the remaining coastal populations north to Los Angeles and Ventura

Public Draft

Counties (considered part of the widespread desert subspecies anthonyi) are similarly imperiled. Widespread *anthonyi* of the Mojave and Colorado Deserts has no formal status.

- **Le Conte's thrasher** (*Toxostoma lecontei*). Although this is an important planning species in the California deserts, the nominate subspecies of the Mojave and Colorado Desert has no formal BSSC status (such status applies only to the San Joaquin Valley population; Shuford and Gardali 2008).
- **Common yellowthroat** (*Geothlypis trichas*). Only the San Francisco Bay subspecies *sinuosa* has BSSC status; breeding populations and widespread migrants on the deserts have no formal or informal conservation status.
- **Rufous-crowned sparrow** (*Aimophila ruficeps*). Only the northern Channel Island endemic subspecies *obscura* has BSSC status. Otherwise this species is west of the deserts, except for small, local populations of the interior subspecies *scottii* in the higher portions of the eastern Mojave Desert, which have no formal status but which should be addressed if its limited habitats undergo potential impact.
- **Sage sparrow** (*Amphispiza belli*). Although cismontane nominate *belli* has shown local declines, it is not present in the deserts. Formal status (ESA Threatened and BSSC) applies only to the endemic subspecies of San Clemente Island. The breeding subspecies in the DRECP planning area is *canescens*; it has no formal status but may be an important indicator species of alkali scrub and other desert scrub habitats.

The following species should be ***retained*** on the list of potentially covered species, although their designations need modification in Table 1:

- **Snowy plover** (*Charadrius alexandrinus*). Delete ESA Threatened designation in Table 1, which only applies to coastal populations (to 50 miles inland, which might border portions of the planning area, e.g. in the Lancaster area); add California BSSC designation (which applies to interior California populations).
- **Willow flycatcher** (*Empidonax traillii*). Add ESA Endangered status, which applies to the subspecies *extimus* ("Southwestern Willow Flycatcher") which breeds along the lower Colorado River and (at least formerly) elsewhere in desert riparian areas.
- **Bendire's thrasher** (*Toxostoma bendirei*). Add California BSSC designation.
- **Yellow warbler** (*Dendroica petechia*). The table should clarify that both the subspecies *sonorana* (lower Colorado River) and *brewsteri* (widely in cismontane California, and locally in desert riparian areas) are listed as California BSSCs and treated in separate accounts in the BSSC publication (Shuford and Gardali 2008).

The following species should be considered for ***addition*** to the list of covered species by virtue of conservation status:

- **Fulvous whistling-duck** (*Dendrocygna bicolor*). California BSSC; breeds (now very rarely) in freshwater areas along and bordering the southern portion of the Salton Sea, and regular but declining as a post-breeding visitor to that area. All Salton Sea bird species are potentially impacted by geothermal and solar energy development and associated transmission lines.

Public Draft

- **Redhead** (*Aythya americana*). California BSSC; breeds locally in desert wetlands, including Piute Ponds on Edwards AFB, wetlands in eastern Kern County, and the Salton Sea.
- **California brown pelican** (*Pelecanus occidentalis californicus*). Although recently de-listed by ESA and CESA, the California brown pelican remains a California Fully Protected Species, and de-listed species still require conservation monitoring and protection. This species is a regular visitor (mainly in summer and fall) to the Salton Sea and has made breeding attempts there. It occurs only casually elsewhere on the California deserts.
- **Least bittern** (*Ixobrychus exilis*). California BSSC (breeding populations); a local breeder in freshwater wetlands on the deserts; more numerous at the Salton Sea and elsewhere in the Imperial Valley and lower Colorado River.
- **Wood stork** (*Mycteria americana*). California BSC. Regular post-breeding visitor from colonies in Mexico to the southern (mainly southeastern) shoreline of the Salton Sea and nearby freshwater lakes.
- **Northern harrier** (*Circus cyaneus*). California BSSC (breeding populations); local breeder in marshes and (after years of high rainfall?) annual growth in the Imperial Valley and Mojave Desert.
- **Peregrine falcon** (*Falco peregrinus*). Although recently de-listed by ESA and CESA, such de-listed species still require conservation monitoring and protection.
- **Lesser sandhill crane** (*Grus canadensis canadensis*). California BSSC; wintering population in the Imperial Valley and probably lower Colorado River
- **Greater sandhill crane** (*Grus canadensis tabida*). California ESA Threatened; small numbers likely winter population in the Imperial Valley.
- **Van Rossem's gull-billed tern** (*Gelochelidon nilotica vanrossemi*). California BSSC; candidate for ESA Threatened/Endangered species status as of June 2010. Breeds at the Salton Sea (mainly southern end); also uses upland and agricultural areas of Imperial Valley for foraging.
- **Elf owl** (*Micrathene whitneyi*). California ESA Endangered. Highly endangered and nearly extirpated from California, with very local breeding populations (most now eliminated) along the lower Colorado River and west to Corn Spring in the Chuckwalla Mountains.
- **Long-eared owl** (*Asio otus*). California BSSC (breeding populations). Local breeder on the California deserts.
- **Short-eared owl** (*Asio flammeus*). California's BSSC (breeding populations). Very localized breeder on the California deserts.
- **Purple martin** (*Progne subis*). California BSSC (breeding populations). Although this species is not known to breed in the desert planning area, some of the few extant breeding colonies in southern California are near the western edge of the deserts (e.g. Tehachapi Mountains, Cajon Pass area, mountains of San Diego County) and foraging birds may utilize the fringes of the deserts and/or be impacted by transmission corridors coming from the deserts.

Public Draft

- **Bank swallow** (*Riparia riparia*). California ESA Threatened. Migrant through the California deserts, with concentrations regularly noted at wetland areas such as Piute Ponds and the Salton Sea. Nests just north of the planning area in the northern Owens Valley.
- **Inyo California towhee** (*Pipilo crissalis eremophilus*). California ESA Endangered; ESA Threatened. It appears that most or all habitat occupied by this subspecies is outside the planning area, but given the potential for shifting or undiscovered populations and slight seasonal movements this taxon should still receive consideration.
- **Large-billed savannah sparrow** (*Passerculus sandwichensis rostratus*). California BSSC. Regular post-breeding visitor to the shoreline of the Salton Sea, especially at the southern end.
- **Grasshopper sparrow** (*Ammodramus savannarum*). California BSSC. Scarce migrant and possibly local breeder on the California desert margins.
- **Tricolored blackbird** (*Agelaius tricolor*). California BSSC and BLM Sensitive Species; potential ESA listing. Important colonies are located in the western Mojave Desert from the western Antelope Valley east to the Victorville/Newberry Springs area; desert agricultural areas and livestock ranches form important wintering habitat.
- **Yellow-headed blackbird** (*Xanthocephalus xanthocephalus*). California BSSC. Breeds locally on the deserts from the Owens Valley and western Antelope Valley south to the Salton Sea and lower Colorado River.
- **Arizona Bell's vireo** (*Vireo bellii arizonae*): CESA Endangered; populations along the lower Colorado River and in riparian washes west of the river north to Inyo County are relevant to the DRECP.

The following species should receive consideration in desert planning by virtue of being listed as USFWS "Birds of Conservation Concern" within the relevant "Bird Conservation Region" (in the case of the Mojave and Sonoran Deserts, BCR #33). Some of these are already on the list of covered species; for those that are not we provide the scientific name.

- Least bittern
- Bald eagle
- Peregrine falcon
- Prairie falcon (*Falco mexicanus*)
- Black rail
- Snowy plover
- Mountain plover
- Whimbrel (*Numenius phaeopus*)
- Long-billed curlew (*Numenius americanus*)
- Marbled Godwit (*Limosa fedoa*)
- Red knot (*Calidris canutus roselaari*)
- Gull-billed tern
- Black skimmer (*Rynchops niger*)

Public Draft

- Yellow-billed cuckoo
- Elf owl
- Burrowing owl
- Costa's hummingbird (*Calypte costae*)
- Gila woodpecker
- Gilded Flicker
- Least Bell's vireo
- Gray vireo
- Bendire's thrasher
- Le Conte's thrasher (*Toxostoma lecontei*)
- Lucy's warbler
- Sonoran yellow warbler
- Black-chinned sparrow (*Spizella atrogularis*)
- Lawrence's goldfinch (*Spinus lawrencei*)

2.5.3 Reptiles and Amphibians

The following species are recommended for ***deletion*** from the list as not occurring in the DRECP planning area or unlikely to be affected by plan actions:

- **Common ensatina**
- **Orange-throated whiptail**
- **Rubber boa**
- **Tehachapi Mountains slender salamander**
- **Western skink**
- **Panamint Mountains alligator lizard.** The advisors believe that this species is outside of the DRECP planning boundary within the Panamint, Inyo, and Argus mountain ranges.
- **Inyo Mountains slender salamander.** The advisors believe that this species is outside of the DRECP planning boundaries within the Inyo Mountains.

The following species are recommended to be ***retained*** on the list because they may occur in the planning area and have restricted distributions, are restricted to special features or other isolated habitats (e.g., sand dunes, wetlands, rock outcrops, riparian zones), or are listed as being of conservation concern. Developments that fragment their habitats, alter ecosystem processes (wind/sand flow to dunes, reduce water infiltration or increase groundwater extraction damaging wetlands), or increase access for collectors will reduce the sustainability of these populations.

- **Western pond turtle.** This species occurs in Afton Canyon and at Camp Cady along the Mojave River and could be adversely affected by any actions affecting the watershed.
- **Arroyo toad.** This species at least formerly occurred in Afton Canyon along the Mojave River. The advisors are unsure whether this population is extant. We recommend surveys or interviews with species experts, and avoiding any actions that could affect the Mojave River watershed.

Public Draft

- **Coachella Valley fringe-toed lizard**
- **Colorado Desert fringe-toed lizard**
- **Mojave fringe-toed lizard**
- **Flat-tailed horned lizard**
- **Desert tortoise**
- **Barefoot gecko**
- **Gila monster**
- **Couch's spadefoot toad**
- **Gilbert's skink**

2.5.4 Fish

A variety of rare, endemic pupfishes (*Cyprinodon* spp.) are found in springs, streams, and swamps in the DRECP plan area. Any activities that affect ground or surface waters may affect these isolated habitats and could adversely affect these unique fishes. We recommend consulting an independent scientific expert on these species (e.g., Don Sada, Desert Research Institute, Reno, Nevada) to determine whether any could be affected by plan actions and should be added as potentially covered species. The plan should thoroughly consider and avoid potential effects of renewable energy projects on surface or ground water hydrology.

2.5.5 Invertebrates

Accounting for and conserving invertebrates, especially arthropods, is difficult but necessary for a successful conservation plan. Although invertebrates comprise more than half the biodiversity in terrestrial ecosystems, most groups of insects and other arthropods are poorly known, with numerous undescribed species (New 1993, 1999, Redak 2000, Wilson 1988). Nevertheless, arthropods provide crucial ecological functions, including pollination, herbivory, and decomposition, that strongly influence the structure and function of natural communities. The advisors noted that arthropods were grossly underrepresented in the proposed list of covered species, with only a single endangered butterfly on the list (Quino checkerspot; *Euphydryas editha quino*)—and that species has not been recorded in the planning area, as it is associated with coastal sage scrub habitat to the west. There are nevertheless many sensitive species of invertebrates in the planning area that should be considered for coverage. For example, Table 2 lists desert insects recently reviewed as candidates for threatened and endangered status (to date USFWS has ruled that there is insufficient evidence to list any of these species). Regardless of their legal status, these species may be at risk and are representative of unique habitats, such as dunes and sand plains. Furthermore, Bunn et al. (2007) listed 28 California-endemic, special status invertebrates in the Mojave Desert and 13 in the Colorado Desert. We recommend a thorough review of available information on the status and distribution of rare and endemic invertebrates in the planning area, including interviews with experts, to assemble a list of invertebrates for consideration as covered species. Appendix C lists individuals having pertinent expertise that should be contacted for input.

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Table 2. Desert invertebrates recently considered for threatened and endangered status (Federal Register 71(160) 47765-47771. 2006).

Common Name	Scientific Name	Order
Sand wasp	*Microbembix elegans*	Hymenoptera
Sand wasp	*Stictiella villegasi*	Hymenoptera
Solitary bee	*Perdita algodones*	Hymenoptera
Solitary bee	*Perdita glamis*	Hymenoptera
Vespid wasp	*Euparagian*. sp.	Hymenoptera
Velvet ant	*Dasymutilla nocturna*	Hymenoptera
Velvet ant	*Dasymutilla imperialis*	Hymenoptera
Algodones sand jewel beetle	*Lepismadora algodones*	Coleoptera
Algodones white wax jewel beetle	*Prasinalia imperialis*	Coleoptera
Algodones croton jewel beetle	*Agrilus harenus*	Coleoptera
Hardy's dune beetle	*Anomala hardyorum*	Coleoptera
Scarab beetle	*Cyclocephala wandae*	Coleoptera
Ruth's dune weevil (new subspecies 1)	*Trigonoscuta rothi rothi*	Coleoptera
Ruth's dune weevil (new subspecies 1)	*Trigonoscuta rothi algodones*	Coleoptera
Ruth's dune weevil (new subspecies 1)	*Trigonoscuta rothi imperialis*	Coleoptera
Ruth's dune weevil (new subspecies 1)	*Trigonoscuta rothi punctata*	Coleoptera

After compiling a list of potential invertebrate species of concern, an effort should be made to establish their distributions in the plan area. This could be done once a draft DRECP is developed by holding taxonomic-focused meetings involving individuals listed in Appendix C, and by examining collections and databases from the following museums:

- Entomology Research Museum, University of California, Riverside
- Bohort Entomology Museum, University of California, Davis
- Essig Entomology Museum, University of California, Berkeley
- Natural History Museum of Los Angeles
- California Academy of Sciences
- Natural History Museum of San Diego County

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Examination of these collections will likely lead to further examinations of additional private and public collections. The goal should be to establish maps of current and historic distributions of rare invertebrate species. Gaps in distributions should be surveyed. Existing location data for arthropods is biased towards easily accessible roads, such that historical distributions may be misleading.

2.5.6 Plants

Table 1 appears to include only plants protected under the state and federal Endangered Species Acts. A much larger suite of rare plants should be considered as potentially covered species, including all species recognized by the California Native Plant Society's (CNPS) as "1B List" and "List 2" plants (Appendix D–DRECP Recommended Covered Plant Species). The 1B designation identifies plants known to be rare, threatened, or endangered in California and elsewhere. The "List 2" designation identifies plants known to be rare, threatened, or endangered in California but more common elsewhere. Despite List 2's wider distribution, these species are rare in California, and their inclusion as covered species helps to realize the NCCP goal of protecting California's biodiversity. As with the rare vegetation alliances, high priority for conservation should be focused on those rare plants that have a threat ranking of 0.1 (Seriously threatened in California; high degree/immediacy of threat) or 0.2 (Fairly threatened in California; moderate degree/immediacy of threat).

In June 2010, the CNPS Rare Plant Program developed a list of rare, threatened, and endangered desert plants potentially affected by the footprints of wind and solar projects proposed up to that time in the California Desert. This list of high priority "at risk" species includes rare plants with occurrences documented by the California Natural Diversity Data Base that fell within a proposed project footprint and/or within a BLM Solar Energy Study Area (SESA) as of June 2010 (Appendix E). GIS layers used in this analysis include:

- BLM renewable energy project layers
- DFG renewable energy project layers
- RETI renewable energy project layers
- RETI transmission line layers
- RETI substation layer
- BLM SESA layer
- REAT RESA layer

The list of affected species considered at high to moderate risk from renewable energy projects contains 171 taxa, of which 102 are on CNPS List 1B, including 14 federally endangered species, 5 federally threatened species, and 1 federal candidate for listing (also California endangered), and 10 California endangered species. Sixty-nine additional taxa are on CNPS List 2. List 1B plants are considered special-status species by BLM, and both List 1B and List 2 taxa meet the definition of rare under CEQA. Thus, these plants require mitigation under either NEPA and/or CEQA.

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Similar to the unusual plant assemblages and rare vegetation alliances, our knowledge of the distribution of rare plants in the California deserts is currently incomplete. For this reason, the advisors recommend that additional season-appropriate surveys conducted throughout the desert regions be incorporated into the database for the DRECP, and recognized and incorporated through the adaptive management strategy.

2.6 Additional Planning Species

The advisors recommend considering whether the list of covered species should be supplemented with additional *planning species* that can assist with meeting plan goals (e.g., because they may serve as easily monitored "indicators" of environmental conditions). Specifically, we propose a method modified from Lambeck (1997), who suggested that conservationists identify groups of species whose vulnerability can be attributed to a common cause, such as loss of habitat area or alteration of a natural disturbance regime. Species in each group can then be ranked in terms of their vulnerability to those threats, and the most vulnerable members may be used as indicators for the group. Often, but not always, such indicator species are listed as threatened or endangered or likely to be listed in the future. This process has been used in California to select focal bird species for seven of the eight habitat-based bird conservation plans, as described by Chase and Geupel (2005). California Partner's in Flight (2009) recently completed a conservation plan for desert birds that should also be consulted.

Lambeck identified four functional categories of focal species. For each group the focal species are those most demanding for the attribute that defines that group and which therefore serve as the "umbrella" species for that group. Together, these species tell us what patterns and processes in the landscape must be sustained in order to sustain biodiversity. Their collective needs define conditions and thresholds—such as patch size, connectivity, fire frequency, etc.—that must be met if the native biota is to be maintained (Lambeck 1997).

- *Area-limited species* have large home ranges, occur at low densities, or otherwise require large areas to maintain viable populations. Examples include large mammals (such as bighorn sheep) and large raptors (such as golden eagle or California condor).
- *Dispersal-limited species* are limited in their dispersal capacity, sensitive to particular movement barriers such as highways or canals, or are vulnerable to mortality when trying to move through human-dominated landscapes. Examples include numerous amphibians and reptiles (e.g., desert tortoise), large-seeded herbaceous plants (Layne locoweed, *Astragalus laynei*), and species sensitive to roadkill (such as desert tortoise).
- *Resource-limited species* require resources that are at least occasionally in critically short supply. Good examples for DRECP include species that rely on wetlands and open water, such as the southern yellow bat (*Lasiurus ega*), which is restricted to unburned palm oases.
- *Process-limited species* are sensitive to details of the disturbance regime (e.g., the frequency, severity, or seasonality of floods or fires) or other manifestations of natural processes, such as hydroperiod, fire-return intervals, or the flow velocity of streams. Examples include species associated with active sand dunes, which relay on wind-transport of sands; perennial plants that require extremely low fire frequency (e.g. blackbrush, *Coleogyne ramosissima*, and Joshua tree; DeFalco et al. 2010); and playa invertebrates, such as fairy shrimp, that require inundation for the completion of their life cycles.

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To this list we add one category:

- *Keystone species*, which exert a disproportionately strong influence on community structure or function due to their physical or biological effects on ecosystems and their interactions with other species (Soulé et al. 2003). Examples include top carnivores (like cougar) that may provide top-down regulation of food webs (Soulé and Terborgh 1999). Some keystone species are also known as *ecosystem engineers* because they physically alter the environment to create habitat features used by other species. Examples include burrowing animals (like tortoises, badgers, and kangaroo rats) that provide microhabitats and homes for numerous other species, and harvester ants, which significantly alter soil structure and nutrients, influence desert seed banks, and hence vegetation (DeFalco et al. 2009). Creosote bush (*Larrea tridentata*) can be considered an ecosystem engineer because its long lifespan enables accumulation of eolian sediments around its base, forming coppice mounds that provide habitat for annual plants and serve as substrate for numerous burrowing animals, including desert tortoises and rodents.

We suggest that plan participants review the list of potentially covered species to see whether they adequately represent this range of functional categories for broadly defined natural communities (one approach might be to use vegetation Classes and Subclasses as listed in Appendix B as a basis for defining broad natural communities, but this deserves further consideration and discussion). A table or matrix that categorizes species by functional category and community type could be used for this purpose. For categories or communities not adequately represented by the existing covered species list, consider supplementing the list with additional planning species to ensure that all communities and essential processes are addressed.

Regardless of whether the plan uses this structured approach to adding planning species, we recommend considering the needs of at least the following species in designing the reserve and developing mitigation, management, and monitoring plans, even though these species are not listed or are unlikely to be listed as Threatened or Endangered:

- **American badger** (*Taxidea taxus*)**.** Badgers are uncommon and declining indicators of open habitats in California (Williams 1986, Quinn 2008). They require very large landscapes and are highly sensitive to habitat fragmentation and roadkill (Quinn 2008, Crooks 2002). They are also important keystone species due to their burrowing activities.
- **Golden eagle**. Eagles are protected above and beyond the measures of the Migratory Bird Treaty Act by the Bald and Golden Eagle Protection Act (16 U.S.C. 668-668c), enacted in 1940. However, the wide-ranging Golden Eagle is also a key planning species because of the large individual home range, reliance on healthy populations of native vertebrate prey (particularly lagomorphs, especially *Lepus*), high susceptibility to disturbance by humans at nest sites, and vulnerability to collisions with power lines and wind turbines (Kochert et al. 2002).
- **Joshua tree** (*Yucca brevifolia*). The Joshua tree is widespread in the Mojave Desert where it is susceptible to fire associated with invasive grasses (DeFalco et al. 2010) and climate change (Cole et al. In Press). Both living and dead Joshua trees provide nesting platforms for raptors and passerines, including red-tailed hawks (*Buteo jamaicensis*), golden eagles (*Aquila*

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chrysaetos), loggerhead shrikes (*Lanius ludovicianus*), Scott's orioles (*Icterus parisorum*), and Cassin's kingbirds (*Tyrannus vociferans*). They also provide the only cavity spaces over large areas for such species as ladder-backed woodpeckers (*Picoides scalaris*), Northern flickers (*Colaptes auratus*), small owls, and brown-crested flycatchers (*Myiarchus tyrannulus*). Such reptiles as the night lizard (*Xantusia vigilis)*, desert spiny lizard (*Sceloporus magister*), and night snake (*Hypsiglena torquata*) are also closely associated with live or dead Joshua trees. Invertebrates are famously associated with tree yuccas in the obligate mutualism of the yucca moth (*Tegeticula* spp.), and a host of other species feed on all parts of the Joshua tree. Another recently described association of the Joshua tree is the relationship with desert rodents which cache and eat the seeds (Vander Wall et al. 2006, Waitman 2009). Evidence of the sensitivity of Joshua tree distribution to climate change occurs in the fossil record (Cole et al. In Press).

- **Ironwood** (*Olneya tesota*). The ironwood is a keystone species in the Sonoran Desert due to its influence on soil nutrients and the food and cover it provides for a variety of desert biota (Nabhan and Carr 1994). Ironwood provides nesting platforms and cavities for nesting birds, and its dense canopy is utilized by nearly 150 bird species. The ironwood is the last in a phenological series of desert tree legumes to bloom following mesquite and palo verde. The Ironwood provides sustenance to invertebrates and thereby food for migrating and resident birds. In addition, ironwood is one of the longest-living plants in the Sonoran Desert, with individuals living well over 1000 years, so it serves as an extremely long-term component over centuries of extreme drought in providing a micro-habitat with less direct sunlight, lower surface temperatures, more organic matter, higher water availability, and protection from herbivores. Over the lifetime of one tree, more than 230 plant species have been recorded starting their growth within the protective microclimate under ironwood "nurse plants" (Nabhan and Carr 1994). This also creates an optimum wildflower nursery which is foraged by rabbits, bighorn, and other native species. An extraordinary level of biodiversity is created by ironwoods, including many dozens of species of bees, ant colonies, and other insects.
- **Blackbrush** (*Coleogyne ramosissima*). Near monospecific stands of blackbrush occur in the Mojave Desert on old geomorphic surfaces with substantial calcrete in the underlying soil horizons. These stands, typically at intermediate elevations and occasionally with significant populations of Joshua trees, typically have high levels of non-native annuals, notably red brome (*Bromus madritensis* ssp. *rubens*), which provide the fine-fuel loading for wildfire, and blackbrush itself is highly flammable. As a result, a disproportionate number of fires, and particularly ones covering larger areas, occur in this vegetation alliance (Brooks and Esque 2002, Brooks and Matchett 2003, 2006). Recent work on the Nevada Test Site (Esque and Webb, unpublished data) suggests that a large amount of the area occupied by near-monospecific stands of blackbrush are burning, and previous work has suggested that natural recovery of blackbrush stands may require millennia (Webb et al. 2009b). We believe there is a pressing need to preserve the remaining area of this unique vegetation alliance from human-induced ignition.
- **Spiny hopsage** (*Grayia spinosa*). The presence of this species is thought by some indicative of suitable habitat for Mojave groundsquirrel, although it is uncertain whether the species itself contributes to habitat quality for this animal.

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The following bird species were selected by CalPIF (2009) as desert focal species because they use desert vegetation as their primary breeding habitat, they are great enough in abundance to provide adequate sample sizes for statistical comparisons, and they have experienced reductions from their historical breeding range. They should therefore be considered as potential planning species for DRECP.

- **Costa's hummingbird** (*Calypte costae*).
- **Ladder-backed woodpecker** (*Picoides scalaris*).
- **Ash-throated flycatcher** (*Myiarchus cinerascens*). Although this species is common and widespread, it is an obligate cavity nester and therefore can serves as a surrogate for assessing nest site availability for desert cavity-nesting species.
- **Verdin** (*Auriparus flaviceps*).
- **Black-tailed gnatcatcher** (*Polioptila melanura*).
- **Le Conte's thrasher** (*Toxostoma lecontei*).
- **Crissal thrasher** (*Toxostoma crissale*). This species is of interest because it occupies two very different desert woodland types – mesquite and riparian in the lower deserts, and pinyon-juniper woodland in the higher areas of the eastern Mojave Desert.
- **Phainopepla** (*Phainopepla nitens*). Phainopeplas provide important ecological services (dispersal of mistletoe seeds).
- **Black-throated sparrow** (*Amphispiza bilineata*).
- **Scott's oriole** (*Icterus parisorum*). This is a focal species in the analysis of desert woodlands (Joshua tree and pinyon-juniper).

The following bird species may also require attention in conservation planning and project siting analysis for various reasons:

- **Common raven** (*Corvus corax*). In recent years, raven populations have increased enormously in the Mojave Desert due to human activities that provide food and habitat structure (Boarman 1993, Boarman and Berry 1995). As subsidized predators, ravens can do significant harm to populations of sensitive species, including desert tortoise and various lizards and other small vertebrates. CalPIF (2009) designated the common raven as a planning species because it is widespread in desert habitats, is in part a human commensal, thrives in developed and disturbed lands and where nest sites are provided by transmission lines and other human-built structures, and is a known and significant subsidized predator on a variety of sensitive species.
- **Harris's hawk** (*Parabuteo unicinctus*). Very localized resident (though largely extirpated) along the lower Colorado River and occasionally in desert woodlands farther west.
- **Greater roadrunner** (*Geococcyx californianus*). Widespread in the deserts, but of interest because severe declines of cismontane populations indicate a lack of compatibility with large-scale development (in addition to its iconic status as a quintessential desert bird).

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- **Brown-crested flycatcher** (*Myiarchus tyrannulus*). Very localized secondary cavity nester in desert riparian habitats (formerly listed as a California BSSC).
- **Scrub jay** (*Aphelocoma californica*). Two subspecies are localized on the California deserts. *A.c. cana* on Eagle Mountain in Riverside County, and *A.c. nevadae* [alternatively called *A.c. woodhousei*, though most authors restrict that name to a more easterly population] in the montane woodlands of the eastern Mojave Desert.
- **Pinyon jay** (*Gymnorhinus gymnorhinus*). A localized pinyon-pine specialist found in some of the higher ranges of the eastern Mojave and along the western fringes of the deserts in the Sierra Nevada, San Bernardino Mountains, and San Jacinto Mountains.
- **Juniper titmouse** (*Baeolophus ridgwayi*). Localized resident of pinyon-juniper woodlands in the eastern Mojave Desert.
- **Northern cardinal** (*Cardinalis cardinalis*). Rare visitor to the lower Colorado River, occasionally breeding. Some or most records elsewhere on the deserts may pertain to escapees.

2.7 Special Features

A wide variety of geological and hydrological features provide habitat attributes essential to numerous desert species and communities. The following features should be mapped to the degree feasible and considered in conservation design and project siting.

- **Desert pavement**. Desert pavement is a dense, continuous cover of pebbles and rock fragments resulting from erosional processes over very long periods. They serve to armor underlying soils from wind erosion (Miller et al. 2009). Breaking of pavements by scraping or other mechanical forces can increase erosion and wind-blown dusts. Development should avoid disturbance to desert pavements. The distribution of desert pavements can be obtained from surficial geologic maps, generally published at 1:100,000 scale and available on the internet (e.g., for near Blythe, California, http://ngmdb.usgs.gov/Prodesc/proddesc_76909.htm).
- **Playas**. Playas are alkaline flats or basins where surface water collects following runoff and either evaporates or infiltrates into the subsurface. The interior portions of playas can develop physical crusts that make their silt and clay soils relatively stable to wind erosion if not mechanically disturbed. Playa margins, in contrast, can be sources for windblown dust, particularly if physical and biological crusts are disrupted. Playa dusts also contain concentrations of toxic substances, such as arsenic and other heavy metals (Chaffee and Berry 2006). Maintenance of crusts and perennial vegetation will reduce dust emissions. Energy projects should avoid use of playa surfaces and only use playa aprons if surface disruption is minimal and vegetation cover is minimally disturbed.
- **Alluvial fans and bajadas**. Alluvial fans are fan-shaped deposits formed where fast-flowing streams exit canyons onto flatter plains. The coalescing of adjacent alluvial fans into a single apron of sloping deposits is called a bajada. Sediments are deposited on alluvial fans by two fluvial processes, streamflow flooding and debris flow. The slowing of floodwaters as they enter and spread over alluvial fans creates gradients of particle sizes, with larger rocks generally deposited near the top of the fan and progressively smaller rocks and soil particles farther down, concluding in fine silts and clays where the fan may terminate in a playa.

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Debris flow can transport large particles long distances downslope from mountain fronts onto alluvial fans and create a complex spatial arrangement of particles. Both processes create physical gradients of particles and soils that provide spatially varied habitats for different types of plants and animals. Groundwater recharge is extremely rare in the deserts, and typically only occurs at the top of fans near major mountain fronts or, to a lesser extent, along ephemeral washes that extend downslope through the fans. Disruption of these ephemeral washes, and particularly blockages of washes upslope of mountain fronts, will negatively influence groundwater recharge and should be avoided. Finally, sheetwash, particularly following summer thunderstorms, creates habitat-sustaining runon on low-slope settings, sustaining desert ecosystems that otherwise would be more xeric. Disruption of sheetflow systems using diversion berms or channelization should be avoided.

- **Biological soil crusts**. Biological soil crusts are soil surface communities of mosses, fungi, algae, and bacteria that are particularly well developed where winter rains dominate. They provide armoring of the soil surface, reduce erosion from water and wind, and create a roughened surface where seeds may be caught. They also help with varied biogeochemical cycling, decomposition, and fixation of nitrogen, which can be a limiting nutrient during wet years. Removal or disruption of biological soil crusts can increase dust production. It can also limit primary production, especially of desert annuals, an important food source for many desert animals. Siting of developments should avoid disruption of biological soil crusts, which may require millennia to recover (Webb et al. 2009b).
- **Cliffs.** Vertical cliff environments provide uniquely harsh thermal and hydraulic environments that tend to have reduced but unique vegetation types. Due to their harshness, such sites are difficult to rehabilitate following disturbance. The base of these vertical habitats provide unique run-on habitats that may be particularly species rich, and production can be quite high depending on soil conditions; however, intense recreational use (e.g., rock climbing) can severely damage these areas. Cliffs provides nest sites and perches for raptor, vultures, and passerine birds, and roost sites for multiple species of bats. Siting renewable energy facilities or transmission lines near cliffs may increase risks to these species. The chuckwalla lizard (*Ater obesus*) and the lyre snake (*Trimorphodon bisctatus*) are also found almost exclusively in this and nearby boulder-rich habitats.
- **Caves and mines**. Caves and mines can be important aggregation sites for several species of bats recommended for coverage (e.g., *Antrozous pallidus*, *Corynorhinus townsendii*, *Myotis occultus*, and *M. velifer*). Although renewable energy developments are unlikely to directly disturb cave and mine habitat, siting wind turbines near caves or mines may increase mortality risks for these species. In addition, renewable energy components close to caves or mines may disrupt microclimate conditions or entry/exit routes of bats. Due to sensitivities about publicly revealing the locations of bat caves and mines, we recommend consulting the California Bat Conservation Plan (currently in preparation) and experts in desert bat conservation (e.g., Dr. Pat Brown-Berry) for information on how best to map or use information on bat caves and mines,.
- **Gypsum-rich soils**. These soils contain high quantities of the mineral gypsum and tend to be harsh environments for desert plants. Those plants that can survive on these conditions tend to speciate rapidly and thus, gypsum soil types often support rare, endemic plant communities.

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- **Riparian channels and washes**. Two types of riparian ecosystems occur in the California deserts. Obligate riparian systems occur along perennial or intermittent streams with shallow groundwater, particularly in alluvial aquifers where a shallow confinement layer or a fault forces water to or near the surface, such as occurs along the Mojave and Amargosa rivers. Xeroriparian systems are more common and occur along large wash systems that have periodic runoff to sustain episodic channel recharge and allow growth of facultative riparian species—notably leguminous trees such as mesquite (*Prosopis glandulosa)*, palo verde *(Parkinsonia* sp.*)* and smoketree (*Psorothamnus spinosus)*. Both types of riparian systems provide high-value wildlife habitat with more abundant food, cover, and other resources than other desert communities. Riparian ecosystems are also naturally resilient, provide linear habitat connectivity, link aquatic and terrestrial ecosystems, and create thermal refugia for wildlife—all characteristics that can contribute to ecological adaptation to climate change (Seavy et al. 2009). Disruption of riparian channels and washes should be strictly avoided by renewable energy developments and associated roads, etc.
- **Seeps, springs, and pools**. All surface waters and shallow ground waters are essential resources for innumerable species in the deserts. Water is a limiting resource for nearly all desert species, and DRECP should avoid any actions that can directly or indirectly affect these resources via changes in ground or surface water hydrology.
- **Sand dunes.** Sand dunes are part of the larger eolian systems of the California deserts that may be either fossil (formed during a different climatic regime), stabilized, or active. All eolian systems were created by a wind system that entrains sediments typically deposited by streamflow, winnows out the fine-grained material and transports it long distances as dust, and transports sand-sized particles that accumulate into dunes. Some eolian systems accumulate sediments as a result of a shifting wind field; this is the typical reason for the formation of star dunes such as the Dumont and Eureka dunes in the northeastern Mojave Desert. Other eolian systems respond to a unidirectional but divergent wind field that results in directional eolian transport and deposition of sands in barcan or linear dunefields, such as those in the Coachella Valley. Sand dunes sustain an inordinately large number of rare, endemic species, particularly on their margins. Developments should avoid eolian surfaces and disruption of eolian-transport areas.

2.8 Ecological Processes

2.8.1 Geomorphology and Hydrology

Geomorphology of the California deserts has a controlling influence on local- and watershed-scale hydrology, primary production of desert vegetation, stabilization against wind erosion and blowing dust, and the habitat usage of animals. The characteristics of desert soils and other geomorphic surfaces develop over millennia, and disturbances to these important characteristics can have ecological ramifications that last indefinitely. Moreover, some geomorphic surfaces, particularly those bearing desert pavements, formed in past climatic regimes and cannot recover following disturbances under today's climate.

Geomorphic systems in the California deserts are unique in North America because the Basin and Range in this region is more tectonically active than areas to the north or east, and the basins generally are closed (unlike those to the east which drain to river systems). Rainfall seasonality

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and intensity varies with elevation and in both north-south and east-west gradients, with the highest annual precipitation in northern areas at higher elevation and the highest proportion of summer rainfall in the eastern and southeastern areas. Desert pavements are more common in the central and eastern portions of the California deserts than in the western Mojave.

Geomorphic surfaces are mapped according to the characteristics and processes of landforms, whether they are sand dunes, colluvial[7] slopes, alluvial fans, ephemeral channels, or playas, and the deposits are the near-surface materials associated with those landforms (Miller et al. 2009). Alluvial fans cover the largest area of concern to solar installations, while mountains are generally the sites for wind turbines. The hydrology of desert mountains is complicated because thin veneers of colluvium underlain by variously weathered bedrock create a complicated flow system for precipitation, which may infiltrate into surficial materials and reach groundwater systems or runoff into ephemeral channels that exit mountain fronts and reach alluvial fans. Mountain front recharge is thought to be the primary means of replenishing groundwater systems that underlie all valleys in the California deserts.

Soil characteristics as influenced by geomorphic surfaces are critical to understanding ecosystem function in North American deserts (McAuliffe 1994, Smith et al. 1995, Stevenson et al. 2009). Soils provide the foundation for terrestrial ecosystems, and small differences in soil properties can have large effects on water-holding capacity and nutrient availability (Comstock and Ehleringer 1992, McAuliffe 2003) which affects plant communities and, in turn, animals communities. Downslope from mountain fronts, depositional surfaces (alluvial fans and other landforms collectively called piedmonts) accumulate sediment eroded from the mountains over geologic time. Most alluvial systems in the California deserts terminate in closed basins known as playas, and some of these are connected via overflow systems that developed during the Pleistocene or earlier in geologic time. Playa margins can, in certain cases, have marginal depositional areas where most of the sediment transported in ephemeral channels is deposited prior to water entering the playa. Sand dunes, sand sheets, and alluvial fans are associated with alluvial depositional areas, generally wide, low-slope areas that include playas and depositional plains (Griffiths et al. 2002).

Plant community composition and primary production vary on piedmonts with characteristics of geologic deposits in addition to elevation and precipitation. Surficial geologic deposits vary in soil particle-size distribution, bulk density, and horizonation of the soil. The particle-size distribution of soils determines water-holding capacity: coarse-grained soils have low water-holding capacity and high infiltration rates, while finer-grained soils, particularly those ringing playas with higher silt/clay content, have high-water holding capacities, low infiltration rates, and particles that can bind nutrients. The particle-size distribution generally decreases downslope from mountain fronts to playa termination in response to channel incision and alluvial fan slope (Blair and McPherson 1994). A wide range of geomorphic features and distinctly different soil characteristics can therefore co-occur in close proximity (McFadden and Knuepfer 1990) increasing the diversity of plant and animal communities on piedmonts.

[7] Materials transported by mast wasting processes, such as landslides and rockfalls.

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The low rates of weathering and soil formation in deserts is caused by low precipitation, with lower relative importance of parent material and vegetation (Jenny 1941). Pedogenesis, or soil formation processes, creates soil layers formed from a combination of weathering of deposits in place, eolian deposition of sediment, and rainwater transport of various chemicals (Pavich and Chadwick 2003). Soil characteristics depend on the physical and chemical properties of the deposited sediments that have weathered in place as well as the characteristics of incoming dust. Surface roughness, which is affected by numerous factors, including surface age and the presence of physical or biological soil crusts, can affect the capture and retention of dust particles, organic material (including seeds), and nutrient status.

Organisms interact with soils through bioturbation, in which plant root growth and the burrowing activities of animals alter soil layering, organic material, and nutrient availability (Belnap et al. 2008). Coppice mounds beneath *Larrea tridentata* (creosote bush)—mounds of typically fine-grained sediments mostly from eolian deposition—are common sites for rodent burrows (Titus et al. 2002). Mounds associated with harvester ant colonies are a mix of surface and subsurface soil and large amounts of organic matter collected by the ants. Desert tortoises, larger mammals, lizards, and snakes all utilize burrows, affecting soil texture and chemistry. Varying soil properties affect desert fauna, which prefer specific soil depths and textures for their burrows (Hafner 1977, Whitford 2002). For example, tortoises tend not to dig burrows in sandy soils because they easily collapse.

2.8.2 Eolian Processes and Dustfall

Movement of soil particles (sand, silt and clay) by wind is one of the dominant processes in dryland environments (Breshears et al. 2003). Soil movement affects ecosystem function by altering soil texture, depth, and chemistry, which can strongly affect plant and animal communities. Alteration of natural soil movement processes by construction or other human effects can have long-lasting impacts that reach far beyond the footprint of the project—for example by increasing atmospheric dusts or by disrupting eolian processes that maintain sand dune communities.

Although there are some soil surface types that are inherently unstable (e.g., playa margins, dry wash bottoms), contrary to common belief, most desert surfaces are very stable and produce little sediment in the absence of disturbance (Marticorena et al. 1997). Natural armoring of the soil surface is provided by rocks, physical and biological soil crusts, plants, and plant litter (van Donk et al. 2003). Construction that disturbs these features can greatly increase soil movements and deposition of soil particles in other locations. Loss of soil via wind erosion leaves behind a coarser textured soil with lower fertility and water-holding capacity. Fine particles (silt and clay) can move great distances on the wind, even around the globe, and degrade air quality and visibility. Deposition of dusts can alter soil fertility and water-holding capacity and therefore plant community composition (Reynolds et al. 2001) often favoring non-native annual grasses (Miller et al. 2006). Dust accumulation on leaves and stems of desert plants can reduce physiological performance, plant growth and seedling establishment (Sharifi et al. 1997, 1999, D.R. Sandquist, pers. comm.). Fine soil particles can also transport and deposit toxic elements, such as mercury and arsenic, onto plants and watersheds (Chaffee and Berry 2006). Sources of such toxicants include mines, mine waste, roads, and other disturbed areas, as well as playas.

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Because sand grains are larger, they tend not to travel so far as the silts and clays that comprise dust. Input of sand onto existing soil surfaces increases water infiltration, dilutes nutrient concentrations, reduces soil surface stability, and restricts the ability of the soils to hold nutrients and water (Breshears et al. 2003). Sand deposition can also bury plants and change which animal species can effectively burrow or live in the area. Wind-blown sands can also break up the physical crusting that stabilizes finer soils and dislodge the fine particles to increase dust flow.

2.8.3 Ecological Range Shifts

It is important that DRECP planners recognize that species' ranges are dynamic and that reliance on static range maps can be misleading. Species' populations naturally fluctuate and shift on the landscape over time due to natural and anthropogenically affected climatic shifts, species interactions, and stochastic population processes. Absence of species occurrences from particular areas or periods should not be considered a permanent condition (except in cases of irreversible habitat conversion), and DRECP should strive for a conservation design that accommodates community and species requirements today and in the future, especially considering likely shifts due to climate change.

In geologic time, North American deserts are relatively young, with their current distributions dating from the late Quaternary (Axelrod 1979). The late Pleistocene through late Holocene warmer-drier climate corresponds with the formation, accumulation and current distribution of sand dunes across western North America (Norris and Norris 1961, Wintle et al. 1994). The species associations that comprise communities and community distributions are therefore recent and likely still in flux. Additionally, species may be expected to experience shifts in their populations due to meta-population dynamics or seasonal changes in their distribution and abundance.

However, these natural fluctuations in the distributions and abundance of desert organisms may be exacerbated by climate change. The southern California deserts are likely to experience a greater shift from current climate means than any North American site south of the Arctic Circle (Kerr 2008). Although changes in precipitation are less certain than those in temperature, there may be increased droughts in the future, and droughts are major forcing functions in desert ecosystems (Hereford et al. 2006). As climate changes there may be areas with "novel climate conditions" that never previously existed within the DRECP. It is difficult to know how desert organisms will respond to such novel climate conditions. Some organisms may shift to track preferred climatic conditions, but others may need to adapt in place to changing conditions—or go extinct—for example for those species that require particular geological substrates or features that will not move. In the future we can expect new associations or communities of species than we see today (Stralberg et al. 2009). Conservation designs based on a concept of ecological stasis, either with respect to species distributions or community associations, are therefore doomed to fail in the long term.

All of this argues strongly for a conservation design that accommodates a changing climatological and ecological landscape by avoiding further fragmentation of the desert landscape, and hence providing maximum potential for species to track their preferred habitat-climate envelopes as conditions change. However, the reality is that our deserts have already

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experienced a large amount of fragmentation from roads, cities, canals, military bases, and other developments. Alternative energy development could further contribute to this landscape fragmentation. Maintaining or improving landscape-level linkages that meet the niche requirements of all covered communities and species should be a key focus of DRECP. Section 4.2 of this report provides detailed recommendations for a robust, interconnected reserve system.

2.8.4 Wildlife Movement and Population Connectivity

Sustaining and enhancing habitat connectivity in the face of energy development, urban sprawl, transportation improvements, off-road vehicle use, climate change, and other stressors is a major conservation concern in California's deserts (Spencer et al. 2010). Populations of many of the region's rare and endemic species—such as the desert tortoise, Mohave ground squirrel, and desert bighorn sheep—are becoming increasingly isolated from one another, leading to decreased genetic diversity and risk of extirpations (Hagerty et al. in review, Epps et al. 2007, Hagerty and Tracy 2010). To counter these effects, various analyses have been recently completed or are underway to identify areas in need of conservation and active management to maintain and improve habitat connectivity and wildlife movement potential. The following references should be consulted by DRECP and used to help site renewable energy developments and conservation actions: the California Essential Habitat Connectivity Project (Spencer et al. 2010), the California Desert Connectivity Project (Penrod et al., in preparation), the South Coast Missing Linkages Project (Beier et al. 2006, South Coast Wildlands 2008), and likely bighorn sheep movement corridors (Epps et al. 2007). Section 4.2.8 provides specific recommendations for incorporating results of these projects and ensuring adequate connectivity in the DRECP reserve design process.

2.9 Environmental Gradients

The advisors recommend careful consideration of how environmental gradients can be used in modeling species distributions, understanding important ecological processes, and guiding conservation design. Environmental gradients are graded spatial variations in some aspect of the physical environment, such as changes in temperature and precipitation with elevation or latitude, ground-water depth with distance from a stream or mountain front, or soil particle size and depth with position along an alluvial slope (see Section 2.8). Many organisms naturally distribute themselves in communities relative to such gradients, and preserving broad, intact gradients may help facilitate adaptation to climate change. For example, some species may adjust to a changing climate by shifting upslope to remain within their preferred niches based on temperature and precipitation gradients (Tingley et al. 2009). Because elevation gradients encompass multiple microclimates within a relatively small area or distance, vagile organisms can potentially shift more quickly in steep areas relative to flatter areas (Loarie et al. 2009), and biotic responses to climate change may be mediated by spatial heterogeneity in the landscape (Ackerly et al. 2010). Elevation and other gradients should be preserved with minimal fragmentation to accommodate potential range shifts. Conservation areas on flatter terrain, or on broad, homogeneous landscapes with little variation in conditions, should be connected to more heterogeneous or topographically diverse areas that provide a greater variety of conditions for species to select from under future climate conditions.

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2.10 Covered Actions

This section briefly summarizes some potential impacts of renewable energy developments on covered species and communities based on our observations as ecologists. This is not a comprehensive review of all potential impacts, because the science advisors are not experts in the design, construction, or operation of energy facilities. We therefore recommend a more thorough and quantitative review of impacts from alternative energy facilities and appurtenances that builds on our initial overview. This comprehensive review should involve individuals with pertinent scientific and engineering expertise concerning the nature of the various technologies and their specific impacts (e.g., experts at the National Renewable Energy Lab [NREL] or other independent and objective experts).

The primary focus of this overview is the potential ecological impacts of large-scale solar and wind energy projects and associated roads and transmission lines. Our review of geothermal energy impacts is more cursory, and we do not specifically discuss the nature of impacts of RPS biomass projects. Some impacts are likely similar among all technologies (e.g., energy transmission from production sites and disturbance of habitat and wildlife during construction). However, different technologies will differ in the nature, extent, and timing of their impacts and therefore will require different siting criteria and different types of monitoring and mitigation. The plan should address at least the following topics with respect to the different technologies in assessing impacts to covered resources, siting of facilities, and mitigation and best management practices for construction and operations.

- Ground disturbance and associated changes in habitat value, erosion, hydrology, etc., probably represents the single greatest impact of renewable energy development, and the amount and distribution of surface disturbance will vary tremendously between different types of energy development. The plan should consider, for example, the relative effects of a single, large, contiguous footprint versus dispersed small footprints in different contexts. It should also recognize that the impacts of developments on desert ecology and covered species can extend well beyond development footprints due to effects on hydrology, eolian processes, and other factors reviewed in Section 2.8.
- If energy facilities are fenced (e.g., for security purposes) they are likely to become barriers to movement for many species. However, fencing may also protect animals from entrapment in degraded, denuded, or dangerous areas.
- Renewable energy facilities and associated utility roads may expand the influence of cities, towns and settlements and provide additional human access to remote desert areas. Different technologies are likely to vary in the amount and distribution patterns of new roads, which increase habitat fragmentation along with a wide variety of direct and indirect adverse effects to desert ecosystems.
- Construction and operation of facilities may require water for cooling, cleaning of equipment, dust control on roads or during construction, etc. The total amount of water required, and sources of this water, should be thoroughly evaluated for each type of facility, with a goal of strictly minimizing total water use over the life of a project.

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- Cables and other linear structures may be buried or above ground. Buried cables will create greater ground disturbance and may disrupt sensitive hydrologies. Aerial cables will disturb the ground for towers, may increase bird fatalities from collisions, introduce perching structures, and increase predation by subsidized predators, such as ravens.
- Renewable energy facilities can have direct effects on wildlife behavior, reproduction, and mortality due to attraction to or avoidance of structures. For example, some species may be attracted to the newly created shade of solar projects, and birds and bats may be attracted to towers or other tall structures. Polarized light reflected from photovoltaic panels creates "ecological traps" for species that mistake the panels for water (Horvath et al. 2010); some birds and insects may be killed by concentrated heat at solar thermal facilities; and many birds and bats are killed by wind turbines (Arnett et al. 2008, Smallwood and Karas 2009).

Table 3 suggests one approach for categorizing differences among technologies in these types of impacts. This approach should be evaluated and completed by DRECP participants, scientists, and engineers having relevant expertise. The following sections elaborate on some of these issues for different types of facilities.

Table 3. A sample approach for categorizing the nature of impacts from alternative development types to guide planning and analysis. This table is tentative and incomplete, and intended only as a sample framework that should be refined and expanded on with input from scientists and engineers more familiar with the impacts of the various technologies.

Criteria	Concentrating Solar	Solar Photovoltaic	Geothermal	Wind
Total Project Area	Low	Low	?	High
Technology Footprint	Contiguous Area	?	?	Highly Dispersed
Surface Disturbance	High	High	?	Low
Road Density	Low	?	?	High
Within-site Transmission Cables	Few	?		Many
Water Use	High	Medium	High	None
Indirect Impacts on Wildlife	Avoidance or Attraction	?	?	Avoidance or Attraction
Direct Impacts on Wildlife	Insects and a few birds killed by heating?	?	?	Collision mortality of bats and birds (insects?)

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2.10.1 Roads

Most renewable energy facilities require access roads, which have a wide array of adverse effects on desert resources:

- Increased access by humans may increase disease incidence in wild tortoise populations via more widespread release of captive desert tortoises carrying infectious diseases (e.g., mycoplasmosis, herpesvirus) (Johnson et al. 2006). Captive tortoises are commonly released in the desert (Murphy et al. 2007) and a recent study in the central Mojave Desert found that wild tortoises with mycoplasmosis were more likely to occur near offices, facilities, urbanized areas and paved roads than in remote areas (Berry et al. 2006).
- Some access roads may need to be regularly graded as maintenance. This often produces berms or deeply incised road beds with steep walls that can entrap animals like desert tortoises and cause death by hyperthermia, increased predation, roadkill, or illegal collecting by humans.
- Access roads (especially those associated with transmission lines) provide food and subsidies for avian and mammalian predators. Subsidized predators (e.g., ravens) use the transmission line towers for nesting, perching, and searching for live prey (tortoises, lizards, other birds and their nests). Prey crossing roads are highly visible to predators, and roadkills provide additional food for subsidized predators.
- Access roads provide sources for invasion and establishment of alien plants along and outward from verges and in disturbed areas associated with power towers and transmission lines. One of the more important factors in alien species richness and biomass of *Erodium cicutarium* is density of dirt roads (Brooks and Berry 2006).
- Recreationists and others use utility access roads for numerous types of activities that can negatively affect vegetation and animals living on adjacent lands. For example, trash and illegal dumping occur along roads, attracting subsidized predators.
- Roads alter the surface hydrology (ephemeral stream channels) which alters vegetation species distributions.

Section 4.3 provides guidance for siting, designing, and implementing actions to mitigate the effects of roads and other barriers to wildlife movement

2.10.2 Transmission Lines

Exhibit C of the DRECP Planning Agreement lists the following sorts of covered actions concerning energy transmission: new foundation, delivery, and connector transmission lines required for accessing renewable energy; transmission upgrades; new transmission lines to connect renewable energy projects to the grid; tower or pole replacements; and substations and switchyards. We assume it will also cover new roads, road improvements or other surface disturbances necessary to access new or existing transmission lines and facilities for construction or maintenance.

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We emphasize that even though the development footprints of transmission poles and towers are not large, that some desert vegetation can be retained within transmission rights-of-way (ROW), and that some wildlife may live in transmission ROWs, the impacts of transmission lines are not as benign to desert resources as sometimes believed. For example, ravens were once rare in the deserts but have become much more common due, in part, to use of transmission structures for perching, roosting, and nesting. Ravens are attracted to developments, dirt and paved roads, water sources, transmission line structures and human habitations (Boarman 1993, 2003; Boarman and Berry 1995; Knight et al. 1993; Kristan and Boarman 2003). Ravens reduce tortoise populations by preying on young tortoises. Tortoises are also killed by vehicles when crossing the transmission line roads, buried by road graders when utility roads are being maintained, and die from overheating when caught between the berms of transmission line roads (K.H. Berry, personal observations). During 2008-2009, ravens attacked adult tortoises in the Central Mojave Desert (A.P. Woodman, personal communication).

Disturbances from construction of new powerlines may also contribute to the invasion, establishment and dominance of alien plants in the Mojave Desert via soil disturbance and transport of seeds by vehicles (summarized in Brooks and Berry 2006, Brooks and Lair 2009).

2.10.3 Solar Projects

The DRECP is to cover both photovoltaic (PV) and thermal concentrating solar projects, including construction of new facilities and substations, expansions or upgrades to existing facilities, and all project related facilities, including roads, utility connects, transmission, water, and gas lines, etc. The greatest impacts to ecological resources, depending largely on siting, are likely to be the direct removal, degradation, and fragmentation of natural communities and habitat and populations of desert species. Because utility-scale solar developments are very land intensive, direct loss of habitat could potentially be highly significant, unless developments can be sited in already disturbed and degraded lands, such as brownfields, former agricultural lands, or previously graded lands. Nevertheless, as discussed in Section 2.8—and regardless of where they are sited—the ecological effects of projects that disturb desert soils can extend far beyond the areal footprint of the development itself due to downslope effects on hydrology and downwind effects on eolian processes, among other effects. Such offsite effects must be accounted for in the siting, design, construction, mitigation, and monitoring of solar energy developments.

Indirect effects of utility-scale solar may be very significant, but to our knowledge they are poorly studied. Indirect effects may include increased light pollution (which can adversely affect nocturnal species); increased dust and sand generation (and potential for toxic chemical deposition, etc.; see Section 2.8); use of water for dust control, cleaning, cooling, or other operations (potentially depleting ground water sources that sustain scarce and essential wetland and water sources for desert ecosystems) ; and changes to local and downslope hydrology (with associated effects to plant and animal communities).

Solar developments may also have significant direct effects on the behavior, reproduction, and mortality of wildlife species. For example, solar panels create a new source of polarized light pollution that can confuse animals that use polarized light for orientation or behavioral cues. Insects that breed over and deposit eggs in water bodies have been shown to be more attracted to

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the strongly polarized light reflections off of solar panels than they are to water. This creates an "ecological trap" for such species, resulting in reproductive failure and direct mortality (Horvath et al. 2010). Birds that are attracted to water sources may also be adversely affected[8]. Moreover, the advisors are concerned that thermal concentrating facilities may kill birds and insects directly via thermal stress.

One peer reviewer of this report raised the issue of elevated local or regional temperatures in the vicinity of large-scale solar developments as a potentially significant adverse effect. The advisors are not aware of any studies of local climate effects of large-scale solar projects, and therefore do not know how significant such impacts might be on desert ecology. We therefore recommend further research on this issue, and certainly monitoring of local climate effects as part of the Adaptive Management and Monitoring Program (Section 6).

2.10.4 Wind Projects

According to the DRECP Planning Agreement, the following types of actions are to be covered: installation of anemometers, new turbine installation, expansion of existing wind projects, upgrades to existing facilities, and project-related facilities like roads, and transmission, water, and gas lines. Although the development footprint of wind towers is relatively small (e.g., compared to solar developments), numerous birds and bats are killed by turbine strikes (Arnett et al. 2008), and wind developments have the potential for significant, regional population effects on some species. Turbine towers can also be used for perching and nesting by raptors and thus may elevate predation levels on nearby prey species.

The California condor is an endangered species that has been reestablished in the Tehachapi Mountains and other California mountain ranges. Populations are expanding in the vicinity of existing wind farms in the Tehachapi Mountains and southern Sierra Nevada. We fear there is a high probability of condor mortalities by turbine collisions during the permit duration.

At least two rare rodents recommended for coverage, the yellow-eared pocket mouse and Tehachapi pocket mouse, have extremely limited ranges that correspond closely with areas of high wind potential on the slopes of the southern Sierra Nevada, Tehachapi, and Transverse Ranges. The rarity of these species suggests that intensive surveys should be performed to identify and avoid occupied or potential habitat areas for direct impacts of wind-farm developments (including roads, etc.). Turbines and other facilities should be designed to eliminate perching by raptors, to avoid elevated predation pressure on these nocturnal rodents, especially by owls.

Bat fatalities have been found at every wind facility in North America that has been specifically monitored for bats. Large fatality events were first documented on forested ridges in the eastern U.S, but more recent studies have documented high fatality rates in plains and agricultural habitats of the Midwest and western Canada (Arnett et al. 2009, Baerwald and Barclay 2009a). Most studies find that migratory species during the migration season account for the greatest

[8] At least one advisor has observed migratory water birds becoming trapped between stacked pipes at construction sites in desert areas, because the birds apparently mistook the pipes as water bodies and attempted to land on them.

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number of mortalities (Arnett et al. 2008). There is little information on bat migration patterns in the desert southwest, but a recent study found that the majority of bat fatalities at a wind energy facility near Palm Springs occurred during presumed periods of migration (Chatfield et al. 2009). This provides hope that fatalities may be somewhat predictable in time and therefore avoidable by managing turbine operations adaptively.

2.10.5 Geothermal Projects

The advisors are not experts in geothermal projects or their impacts on biological resources, and we did not specifically discuss recommendations for such projects. In general, we note that current and proposed geothermal developments occur near the Salton Sea and its various open-water, shoreline, riparian, marsh, and agricultural habitats that support abundant bird life. Associated transmission lines, night-lighting, construction and maintenance activities, and water usage likely have adverse impacts on a number of covered species. It is our observation that impacts of current geothermal development at the Salton Sea have come mainly from their siting (near or even on important wildlife habitat), and some of us have observed mortalities of large birds hitting transmission lines during flight near the Salton Sea. We also note that water consumption of geothermal plants may be a concern (although we understand this varies greatly depending on specific technologies, such as whether and how water is reinjected).

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3 Principles for Addressing Information Gaps and Uncertainties

Gaps in available information on biological resources are always among the biggest sources of uncertainty for regional conservation plans. Here we address some approaches for filling these data gaps and dealing with scientific uncertainty.

3.1 Environmental Base Maps

Accurate and reliable maps of ecological, climatic, and geological features and species distributions are essential to good conservation planning and their lack represents a critical information gap.

3.1.1 Vegetation Maps

For DRECP, accurate, up-to-date, and fine-resolution land cover or vegetation maps are a key data gap. Vegetation mapping is not comprehensive across the plan area, and mapping efforts vary in detail, approach, and accuracy in different regions (Appendix F). Currently, there is no detailed vegetation map, nor a special features map, for the western Mojave Desert. The advisors recommend that both an alliance-level vegetation map and a special botanical or vegetation features map be assembled for this area, much like the one that was developed for the central Mojave (Thomas et al. 2004). While the central Mojave special features map may need updating and refinement, it does represent a well-executed initial effort for defining natural communities. New mapping efforts to assemble an alliance-level map should be based on high quality digital imagery and should be delineated and labeled using standard CDFG vegetation protocols (http://www.dfg.ca.gov/biogeodata/vegcamp/pdfs/Final_SB_85_Report.pdf)**.**

Unfortunately, creating a comprehensive, alliance-level vegetation and special features map for the entire western Mojave region would take approximately 18 months once sufficient funding is provided to secure contract mapping, which would augment mapping that could be accomplished through CDFG's Vegcamp efforts during the same time period (T. Keeler-Wolf, personal communications). Given this is not possible under the DRECP schedule or available funding, vegetation alliance and special features mapping should be prioritized within currently unmapped regions most likely to be affected by renewable energy developments, such as renewable energy study areas in the Western Mojave west of Barstow and around Owens Lake.

An option for providing a useable vegetation map on a rapid schedule would be to create an "interim" or mid-level vegetation map that lacks some of the detail, field survey data, and accuracy assessment needed for a final map, but that would nevertheless be an improvement over the current situation. The interim map could be completed in less than 18 months by compiling new and existing vegetation maps with minor reformatting to allow for standardized representation. It could be produced by photo-interpreters familiar with California desert vegetation and supplemented with field reconnaissance. Individually attributed polygons would contain information on alliance or alliance groups (compliant with the National Vegetation Classification System [NVCS] mid-level hierarchy based on ecologically aggregated groups of alliances [FGDC 2008 in Sawyer et al. 2009]), basic structure (cover classes, height classes), and

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stand quality (attributes for degree of "roadedness," invasive exotic cover, and other easily interpreted attributes). An interim map, as described, would lack the detail needed for a final map, as well as a rigorous accuracy assessment and a complete synoptic revision. In addition, it would not be reliable in all attributes or spatial representation. Nonetheless, it would better determine the distribution of vegetation, including unique or rare vegetation types, than existing, broad-scale, maps. It would also represent an improvement over existing low-resolution vegetation maps for purposes of habitat or species distribution models. The interim map would be merged with re-scaled, existing data-driven vegetation maps for the central and eastern Mojave and several of the large state and national parks to create a single vegetation data layer that would provide an improved, baseline map for regional planning.

However, it is important to recognize that such an interim, mid-scale map is a compromise and should not be considered a final product: We believe that a comprehensive, fine-scale, alliance-level vegetation map supported by rigorous field data collection over multiple years and a formal accuracy assessment per CDFG protocols, should be completed as soon as possible, whether it can be finished prior to the draft DRECP, or after the draft plan for use during plan implementation

See Appendix F for a more comprehensive review and recommendations concerning vegetation mapping in the planning area.

3.1.2 Special or Unique Plant Assemblage Mapping

The advisors recommend that a special features map similar to that created for the Central Mojave Vegetation Database (Thomas et al, 2004) be made for the rest of the planning area. It would serve as a template for the development of a database describing rare or localized vegetation types, habitats or plant species. The Significant Natural Area approach for the western Mojave could be used for this map as several species or vegetation occurrences overlap and can be used to identify spatially explicit units for conservation which would otherwise not be shown on the alliance level vegetation map.

The following excerpts from a metadata report for special features coverage for the Central Mojave Vegetation Database specify methodology that could be used as a model for creating a comprehensive special features map for the entire planning area. Refer to the entire metadata report (see Appendix F) for additional detail on the types of entities covered in the special features layer for the Central Mojave Vegetation Database.

The Central Mojave Special Features coverage is composed of point locations representing a rare/special vegetation alliance, unique stand, or a feature with co-occurring or potential vegetation alliances. Each point location was obtained from existing digital map databases, hard copy source maps, literature descriptions, or field work conducted for this project or other Mojave Desert field projects.

Other special features such as wetlands and rare plant occurrences were added to the point coverage. Locations of springs were added to the Central Mojave Special Features map database from USGS Digital Line Graph (DLG) map databases (1:24,000 and 1:100,000) which resulted in 640 spring locations. Riparian and wetland features for portions of Death Valley were

Public Draft

extracted from the National Wetlands Inventory (NWI) map database. Some of those features are known to be devoid of vascular vegetation (e.g. salt flats); however, other features are known to be vegetated. Point locations for crucifixion thorn (*Castela emoryi*) were obtained from map databases developed by the Bureau of Land Management in association with the Northern and Eastern Colorado Desert planning effort.

3.1.3 Other Important Maps

A variety of existing maps and GIS data layers should be consulted during planning and incorporated into a central GIS database for use in spatially explicit models or other purposes, including:

- Surficial geologic maps available from the California Geological Survey (http://www.consrv.ca.gov/cgs/information/geologic_mapping/Pages/index.aspx) and the U.S. Geological Survey (http://ngmdb.usgs.gov/).
- Soil and substrate geospatial data, which can be obtained from a combination of surficial geologic maps and data developed by the National Resource Conservation Service, including the STATSGO and SSURGO databases (http://soils.usda.gov/survey/geography/statsgo/; http://soils.usda.gov/survey/geography/ssurgo/).
- Disturbance maps (recent or historic ORV, military training, homesteads, agriculture, livestock grazing, brownfields, etc., that would affect soil surface and vegetation). If no existing map combines these sorts of disturbances, such a map should be created to identify preferential areas for siting renewable energy projects. The U.S. Bureau of Land Management, California Desert District, Moreno Valley, has such maps.
- Wildlife linkage, movement corridor, and habitat connectivity maps, including at least the following:
    - South Coast Missing Linkage Project Linkage Designs that are at least partly within the DRECP Area (available at http://scwildlands.org/index.aspx).
    - Least-cost corridor models and habitat suitability models for diverse focal species, and draft Linkage Designs to accommodate a broader range of species are currently being prepared by SCWildlands for the California Desert Connectivity Project (Penrod et al., in preparation).
    - Natural Landscape Blocks and Essential Connectivity Areas mapped for the California Essential Habitat Connectivity Project (Spencer et al. 2010). Links to download the report, maps, and GIS data are at www.dfg.ca.gov/habcon/connectivity/.
    - Dispersal and least-cost path models for desert bighorn sheep identified by Epps et al. (2007).
- Fire maps (contact Matt Brooks at USGS for up-to-date maps).
- Nitrogen deposition maps (from Drs. Ellen Bauder and Edith Allen, UC Riverside).
- Fault lines (associated with concentrations of springs, seeps, and hanging gardens). These can be determined from geologic maps.
- Audubon Important Bird Areas.

Public Draft

- Paleo site data.
- BLM maps of permit applications to identify conflicts between proposed projects and potential reserve areas.
- Maps of critical habitat and/or sensitive habitats for rare, threatened, and endangered species from existing documents.
- Maps of existing or proposed Wilderness; designated Research Natural Areas, Natural Areas, and Areas of Critical Environmental Concern.
- Road density map, with indicating differences between paved roads, dirt or gravel roads, graded or ungraded roads, etc.
- Existing utility lines, corridors, fiber optic cables, aqueducts and other linear features, including information on width of rights-of-way and disturbed areas.
- Map of water sources, springs, seeps, rivers, streams; map of primary, secondary, tertiary and other washes.
- Google Earth is a good aerial imagery tool, especially using the "history" option, which can reveal areas subject to historic disturbance.

Note GIS data layers vary in their reliability, accuracy, and recency. All data should be carefully reviewed and assessed for accuracy in the field prior to use in models or for planning.

3.2 General Information Sources

The following information sources about desert ecology and species should be consulted during plan preparation:

- Berry, K.H., and R. Murphy. 2006. Deserts of the World Part I: the Changing Mojave Desert. Journal of Arid Environments 67, Supplement, Special Issue.
- Pavlik, B. 2008. The California Deserts. University of California Press.
- Rundel, P.W., and Gibson, A.C. 1996. Ecological Communities and Processes in a Mojave Desert Ecosystem, Rock Valley, Nevada. Cambridge University Press, 369 p.
- Shuford, W.D., and T. Gardali (eds.). 2008. California Bird Species of Special Concern: a ranked assessment of species, subspecies, and distinct populations of birds of immediate conservation concern in California. Studies of western birds, no. 1. Western Field Ornithologists, Camarillo, CA. and California Department of Fish and Game, Sacramento, CA.
- Webb et al. 2009c. The Mojave Desert: Ecosystem Processes and Sustainability. University of Nevada Press, Reno, Nevada.
- Whitford, W. 2002. Ecology of Desert Systems. Academic Press, London.
- Wilshire, H.G., J.E. Nielson, and R.W. Hazlett. 2008. The American West at Risk. Science, Myths, and Politics of Land Abuse and Recovery. Oxford University Press, New York.

Public Draft

3.3 Species Locality Data

In addition to CNDDB and other databases maintained by CDFG in the BIOS program (http://bios.dfg.ca.gov/), there are a variety of sources of species locality data that should be incorporated into BIOS or a central DRECP database and used in species distribution modeling, including at least the following:

- California Mammal Species of Special Concern database (MSSC; Spencer et al. in prep; database expected to be available by late 2010; range maps in 2011).
- PRBO Conservation Science and the California Avian Data Center (www.prbo.org/cadc) which is a node of the Avian Knowledge Network.
- Cornell Laboratory of Ornithology's eBird database (http://ebird.org/content/ebird)
- Local BLM offices conducting biotic inventories.
- Museum records. Digital databases are now available for many museum collections, including ORNIS for avian museum databases (http://ornisnet.org/) and MaNIS (http://manisnet.org/) for mammals[9], HerpNET (http://www.herpnet.org/herpnet/index.html) for amphibians and reptiles, and the Consortium of California Herbaria (http://ucjeps.berkeley.edu/consortium/), and the San Diego Natural History Museum's Plant Atlas (http://www.sdnhm.org/plantatlas/index.html) for plants.
- Site-specific information from EIRs and EISs (compiled into a central database).

3.4 Species Habitat Suitability and Distribution Models

Information on species' distribution and abundance are critical inputs to conservation planning. Range maps are not always available for individual species. Survey data may be used to infer distributional limits or abundance if they are comprehensive and collected broadly across the regions. However, because comprehensive survey coverage is not feasible for most species, we recommend judicious use of habitat suitability models or species distribution models (SDMs). SDMs allow point locality data to be extrapolated to determine probability of occurrence maps which may be used to infer species presence or habitat suitability over broad areas, including areas not previously surveyed. Where data are sufficient, empirical or statistical models based on species locality data (or presence-absence data) are preferred. Where data are not sufficient for empirical models, careful use of "expert-opinion" models may be warranted. Moreover, in cases where available survey data are strongly spatially biased, or for species that may have been extirpated from areas of suitable habitat, habitat distribution models based on expert opinion may be more appropriate than models built using species locality data (Early et al. 2008).

3.4.1 Empirical or Statistical Models

Empirical (statistical) modeling approaches are better than simple GIS overlay or "query" models that are often used in conservation plans as proxies for mapping habitat values or

[9] Note, however, that MaNIS data have been incorporated into the MSSC database.

Public Draft

predicting species distributions. Although the overlay method is useful as an initial step for exploring which factors, *of those available in the GIS*, seem to be associated with species occurrences (e.g., they are more useful as *exploratory* rather than *forecasting* models; O'Connor 2002), the resulting maps inevitably contain significant errors if used to represent or predict species distributions, at least in part because they cannot account for interactions among variables in affecting habitat suitability. Statistical SDMs have the added benefit of specifically quantifying uncertainties in model predictions.

Species distribution (or occupancy) modeling is a very active and constantly evolving research field with numerous recent advances (Elith et al. 2006, Elith and Leathwick 2009; http://biodiversityinformatics.amnh.org/index.php?section=sdm_guide). SDMs use environmental variables characterizing places where a species does (or does not) occur based on survey data to develop sophisticated correlative models. SDMs may also be extrapolated to project future occurrences in places where the correlated environmental features are projected to be present in the future (Wiens et al. 2009). Care should be taken to select a modeling approach and SDM algorithm that performs well based on recent peer-reviewed literature and which is appropriate for the organism being modeled. It may be prudent to model the data with more than one SDM algorithm and examine overlap among model outputs ("consensus modeling"), as well as the amount of uncertainty among model outputs (see Wiens 2009 for an example of uncertainty analysis).

We emphasize the importance of expertise and rigor in applying these highly technical models. In our collective experience, this expertise is generally lacking at environmental consulting firms that prepare HCPs, NCCPs, and NEPA and CEQA documents. However, there is a growing pool of appropriate expertise at academic research institutions, science-based NGOs, and science-based government agencies, such as USGS. *We urge DRECP to tap appropriate expertise for the application of any scientific models, because learning-while-doing is inefficient and error-ridden*.

To construct a SDM, the following components and steps are needed: acquisition of biotic inventory data, selection of relevant environmental variables, selection of one or more SDM algorithms, selection of spatial scale, evaluation of model results, and interpretation of the resulting output. All of these steps should be well documented and defended when presenting model output results.

- **Biotic inventory data**: Ideally biotic inventory have been collected over the range of geographic and environmental space that one wants to create a model for. Systematic or random sampling designs are ideal, but almost never possible and not essential. Occupancy modeling approaches (MacKenzie et al. 2006) can control for species detectability and can be used to augment or expand simple presence localities.
- **Algorithm selection**: Ideally, species distribution models should be built using empirical, statistical methods, such as generalized additive models (GAM) or hierarchical regression models (see Scott et al. 2002, Guisan and Thuiller 2005, Beissinger et al. 2006, Elith et al.

Public Draft

2006, and Elith and Leathwick 2009 for recent reviews)[10]. Some algorithms are appropriate for presence-only data (e.g., from museum records or CNDDB), while other algorithms incorporate presence and absence inventory. Because new algorithms are constantly being developed, care should be taken to select an algorithm that has been well documented in the recent peer reviewed literature.

- **Selection of environmental variables**: Carefully think through *all* environmental factors most likely to affect each species' distribution, and how these factors may interact (e.g., vegetation, geologic substrate, terrain, hydrology, climate, insolation, other species). Species experts and the literature should be consulted to determine the relevant environmental factors. Avoid combining redundant (highly correlated) factors within a model, and select those variables most likely to explain variations in habitat quality. In doing this, recognize that there are many useful environmental variables that can be derived from existing GIS layers, such as indices of habitat patch size, fragmentation, distance from water, primary productivity, insolation, or road densities.
- **Selection of spatial scale**: The spatial scale should be relevant for the taxa of interest, as well as incorporating the scale of the environmental variables (e.g., some environmental variables are only available at 800m or 1km sized pixels). The grain size selection may affect model results (Guisan et al. 2007). Most SDMs involve averaging variables over a "moving window" of a size relevant to the species in question, based, for example, on the species' average home range size or the scale at which individuals select habitat areas.
- **Evaluation of model results**: The resulting SDM output should be statistically evaluated. There are a variety of approaches for assessing predictive performance and selecting test statistics. If a model performs poorly it should be documented and potentially re-run with alternate environmental data, additional biotic inventory data, or some other considerations based on input from experts on the taxa. Usually, a variety of alternative or "candidate" models are created using different combinations of variables, where each combination of variables represents a reasonable hypothesis about what factors interact to influence habitat suitability. These candidate models are then statistically compared or "competed" (using information-theoretic metrics) to select a single "best" model or a combination of models that may be averaged together (Burnham and Anderson 2002).
- **Interpretation of output**: Most statistical models produce continuous gradients of a species' probability of occurrence, or at least multiple categories of habitat value, which can be more revealing for conservation planning than discrete suitable/unsuitable habitat maps. Ideally an expert on the taxa can review the final model output. It is important to realize that probability of occurrence is just that: species sometimes are found in places with a low probability of occurrence, and may sometimes be absent from those with a high probability—because random events and stochastic processes are common in nature. Maps that represent habitat in a simple suitable-nonsuitable format, or species occurrence as a simple presence or absence format, are generally misleading.

[10] A number of sophisticated software packages for analyzing species distribution data are now freely available, such as MaxEnt (www.cs.princeton. edu/ ~schapire/maxent).

Public Draft

3.4.2 Expert-opinion Models

Unfortunately, empirical SDM models often require more species location points than are available (especially for rare and endangered species), and they may not be appropriate if there is a great deal of spatial bias in the underlying data or for species that are absent from areas of suitable habitat due to other factors like predation, collecting, or disease, or species with strong metapopulation dynamics that cause populations to appear and disappear in suitable habitat over time (Early et al. 2008). Under such conditions, we endorse cautious use of "expert opinion" habitat distribution models, so long as they adhere to some guidelines to be as reliable as possible.

Base the models as much as possible on peer-reviewed literature, and obtain expert review of models. Use model logic to capture how environmental variables interact to affect habitat value. Most GIS query models use simple Boolean "and" logic (i.e., a species may occur if a site has the right soil AND vegetation AND elevation, etc.). However, other logical interactions (e.g., using Boolean "or" logic) may also apply (i.e., a species may occur in vegetation type A at low elevation, OR type B at higher elevation, etc.). A full review of these concepts is beyond the scope of this report, but we recommend reviewing Scott et al. (2002), Guisan and Thuiller (2005), Beissinger et al. (2006) or other recent reviews of habitat modeling for ideas. Regardless of what model approach and variables are used, uncertainties in model predictions should be clearly articulated and considered in any decisions based on them.

SCWildlands has prepared expert-opinion habitat models for 48 focal species in California deserts for the California Desert Connectivity Project (Penrod et al. in preparation). These models use variable scoring and weighting factors developed by species experts using a variety of available GIS environmental data layers. Data classes relevant to habitat suitability for each species were scored from 1-10, and the scores were combined using weighted arithmetic or geometric means to rank habitat suitability from low to high, using such variables as vegetation type, elevation, terrain ruggedness, distance from water, and road density. The advisors did not have time to comprehensively review the draft SCWildlands models for this report. We recommend that they be subject to peer review to determine their potential utility to DRECP.

3.5 Decision Support Models

Decision support models are increasingly recognized as tools to guide decision making for natural resources and systems in complex landscapes (Llewellyn et al. 1996, Leung 1997, Seavy and Howell 2010). Informed decision making for the addition of renewable energy facilities and their infrastructure to the desert southwest may be greatly facilitated by this process. The benefits of spatially explicit decision support systems include (1) the ability to balance interacting land uses while considering resource values and existing land use agreements, (2) merging data from multiple sources such that potential conflicts, interactions and synergisms can be readily identified and openly discussed among interested parties, (3) analyze landscapes (e.g. this 23,000,000 ac study area) in consideration of realistically complex management situations, and (4) the process is highly documented, repeatable, and can be readily modified to explore alternatives by all interested parties (Heaton et al. 2008).

Public Draft

Within this framework, one important consideration is the nature of the modeling input. Decision support models can be formulated using deterministic and probabilistic data, as well as expert opinion (see Section 3.4). The distinction among these data sources should be explicitly stated within the context of model documentation. Furthermore, any of these data may be available from peer-reviewed documents, gray literature, or expert opinion, and the source of information should also be explicitly stated. The distinction among data sources can have important ramifications for the end product and the integrity of the process. Models based on empirical data and vetted by peer review provide a level of confidence, but availability of such models is limited. In contrast, expert opinion models or models not vetted by the peer-review process are more readily available, but confidence in their outputs is generally lower. Hybrid models based on inputs from all potential data sources may provide the broadest potential for exploring the complex issues related to energy, resources and societal needs and creating realistic scenarios. Therefore hybrid models are a potential construct, but the nature of all inputs should be explained in detail so reviewers understand the limitations and uncertainties.

Acquiring data and ensuring its reliability can be a very challenging aspect of this type of work. To the greatest extent possible, reliable and thoroughly reviewed data sources that are already assembled should be relied on, as data assembly and review is time consuming and expensive. Compatible data sets that are previously assembled and peer reviewed should be acquired and used to the greatest extent possible.

3.5.1 Desert Tortoise Spatial Decision Support Model

An example decision support model with direct applicability to DRECP exists for the desert tortoise. The following information is provided courtesy of Cat Darst of the USFWS Desert Tortoise Recovery Office:

> The Desert Tortoise Recovery Office spatial decision support system identifies and prioritizes actions that are most likely to ameliorate threats to tortoise populations at any geographic extent (>1 square kilometer) within the tortoise's range. To do this, the decision support system utilizes GIS data of the spatial extent of threats (*i.e.*, where threats occur geographically) to calculate how changes in threats contribute to changes in tortoise population numbers.
>
> The decision support system models the relationships between threats, population stresses, and demographic change factors. The relationships within the model are weighted using institutional understanding of the strengths of: (1) inter-threat links, (2) threat to population stress links, and (3) population stress to demographic change links. The GIS data of the spatial extent of threats are then geoprocessed with these weights to calculate how changes in threats contribute to changes in tortoise population numbers and how recovery action implementation is predicted to ameliorate those threats.
>
> Future versions of the decision support system may permit managers to conduct gap analysis on their current/planned recovery actions (*i.e.*, compare ideal to current or planned management actions to identify gaps in management prescriptions for a given area) or to evaluate actions in terms of their near- vs. long-term contribution to recovery. The decision support system may also be used to develop prioritizations that account for economic,

Public Draft

political, and operational constraints that managers face when implementing recovery. All data and underlying models will be updated and evaluated on a regular basis.

The DRECP independent science advisors recommend considering use of the Desert Tortoise Decision Support Model for assessing and comparing plan alternatives, and considering whether similar systems can and should be developed for other resources of interest. If not already done, the model should be subject to peer review before application. Most important, the current environmental data layers used in the model are known to have errors (C. Darst, personal communications) and require updating and corrections before they can be depended on. Nevertheless, given that the input variables are adequate, such decision-support tools could be used to compare the relative likely effects of alternative development-conservation-mitigation-management scenarios on the species, and thereby select combinations of actions most likely to contribute to the conservation and recovery of the species.

3.5.2 Spatially Explicit Population Models

Spatially explicit population models (SEPM) are more quantitative extensions of the sorts of decision- support models discussed above, and provide a powerful means of comparing alternative conservation strategies for rare or endangered species (Carroll et al. 2003, Carroll 2007, Spencer et al. 2008, Carroll et al. In Press, Spencer et al. In Press). SEPMs track the fates of many simulated individuals through time as they move across a grid of cells in a geographic information system (GIS) environment—and grow, reproduce, disperse, and die. The software package HEXSIM (http://www.epa.gov/wed/pages/models/hexsim/index.htm, which updates an earlier version called PATCH; Schumaker 1998), links the survival and fecundity of individuals or groups of animals to data on mortality risk and habitat productivity at the scale of an individual territory (or a pack territory for social groups). Population vital rates can be weighted based on habitat suitability—for example, with higher mortality rates or lower reproductive weights in suboptimal habitats. The behavior of large numbers of individuals, over a large number of replicate simulations (to account for effects of stochasticity) is then used to determine the range of likely fates for the population under alternative scenarios and to assess uncertainties about the likely outcomes. Hence, SEPMS can be used to make relative comparisons of how a population or metapopulation may fare under alternative future scenarios—such as alternative reserve designs, development scenarios, types of management intervention, or assumptions about future climatic or other conditions (Spencer et al. 2008, Carroll et al. In Press, Spencer et al. In Press).

SEPMs are data hungry, however, and are best used on species for which there is reasonably good information on species' demographic rates and processes (e.g., reproductive rates, mortality rates, dispersal characteristics) and how these may vary with habitat condition. We recommend exploring the use of SEPMs to compare among plan alternatives for a few key covered species for which there may be sufficient data to parameterize models, especially desert tortoise and bighorn sheep. Other species for which the approach may be useful (given adequate demographic data) include Mohave ground squirrel, flat-tailed horned lizard, and leopard lizard.

Public Draft

3.6 Anticipating Climate Change

The world of climate-change modeling, and of predicting the responses of species and ecological communities to climate change, is developing rapidly, but large uncertainties remain (e.g., Oreskes 2004, Hayhoe et al. 2004, Wiens et al. 2009, Stralberg et al. 2009, Beier and Brost 2010). What is certain is that desert climates will change to the detriment of many species, and that some species ranges will shift, creating new and novel ecological communities, and thus new interactions with uncertain effects. And, contrary to popular perception, new studies are suggesting that the pace with which species may need to adapt or shift their ranges in response to climate change may be more dramatic in broad, relatively flat terrain (like deserts, plains, and grasslands) than in more dramatic, mountainous terrain (Loarie et al. 2009, Stralberg et al. 2009).

The following concerns about predicting climate-change effects on species distributions are based on comments submitted by a peer reviewer of this report (Dr. James Patton, Professor Emeritus, UC Berkeley): Most climate-effects distribution models have been based on climate variables alone (typically the Bioclim variables), whereas soil types, geological formations, plant communities and other variables are also important to many species. Plant communities will reflect local climates to some degree, but climate alone cannot predict future plant combinations that will be important to animal species. The data points used for distribution modeling are also important: We know that there have been range shifts over the past century, but we don't know if those shifts have been monotonic with time or if an abrupt distributional shift occurred in a particular focal time-period. Studies like the Grinnell Resurvey Project (http://mvz.berkeley.edu/Grinnell/research/index.html) reveal that not all species have shifted their ranges (about 50%), and for those that have, the shift is not always in the same direction. Hence, distribution modeling for two known points in time (early 20th century and today) does not predict current distribution no matter how good the "fit" is for either of these time periods. As a consequence, projecting to the future from today alone for any particular species is problematic at best.

We recommend that participants continue to track the evolving scientific literature on climate change effects in the planning area, *while planning a reserve network that is as comprehensive and robust as possible to this uncertain future*. *This means conserving large areas that encompass broad environmental gradients (e.g., a wide range of latitudinal, longitudinal, elevational, climatic, and geological conditions) within an interconnected reserve network (to allow the greatest potential for range shifts), and that it maximize conservation of ground and surface waters, riparian areas, and washes to maximize resiliency in the face of climate change*.

A promising analytical approach to consider using in designing a reserve system that is robust to climate change is the land-facets approach advocated by Beier and Brost (2010). This approach recognizes that species distributions are largely functions of climate—which changes—in concert with physical attributes of the landscape (especially soils, elevation, topographic position, and exposure to sunlight)—which are much more stable over time. Conserving interconnected areas that represent the full spectrum of these physical, landform attributes, may allow species to shift their distributions with climate change while remaining within their favored physical niche.

The plan should also anticipate the need to monitor and respond to changes via the adaptive management and monitoring program, which will entail establishing comprehensive baseline monitoring stations as soon as possible (Section 6.4).

Where sufficient SDMs exist for species (Section 3.4) based on current climate data, future projections should be made to determine how species distributions may shift under climate change. These sophisticated models should be based on the latest peer reviewed methods and climate models (Wiens et al. 2009) and should include measures of uncertainty where possible.

Public Draft

4 Principles for Conservation and Reserve Design

This section provides a review of the [11]REAT "starting points" maps and recommends approaches for designing an ecological reserve network in the planning area to sustain biological diversity, natural ecological communities, and ecosystem functions. It also provides some guidance for siting, configuring, and mitigating developments to minimize adverse effects to desert ecosystems. Section 5 provides further details for selected covered species and communities.

4.1 Review of REAT "Starting Point" Maps

At our April 2010 science advisors' workshop, REAT representatives presented some preliminary maps intended to help guide where conservation actions and renewable energy developments should be sited. The REAT maps can be improved by more careful use of existing data, increased transparency in methods, and more rigorous application of reserve-design principles and models, as detailed below. Among the potential problems with application of the REAT maps were the following:

Inappropriate use of species locality data points to prioritize areas of conservation concern. We recommend that DRECP a*void using species observation locality data (e.g., from the California Natural Diversity Data Base, CNDDB) as a primary foundation for siting development or conservation actions using GIS overlay models*. Because CNDDB (and other locality databases) are compiled largely from incidental observations, rather than systematic surveys or random sampling programs, they are inherently spatially biased—and *absence of points from a locale cannot be interpreted as absence of the species*. The advisors were not provided details concerning the ranking methods and criteria used to create the REAT "species sensitivity ranking" maps, but we understand that CNDDB data (along with other unspecified data sources) were weighted based on species conservation sensitivities and then combined using GIS overlay techniques. Because we cannot account for spatial survey biases in this approach, the advisors cannot concur with the interpretation that "the darker the color the higher the sensitivity," or conversely, we have no confidence that areas lighter in color are necessarily of lower biological value.

CNDDB data represent an incomplete and inaccurate means for assessing species of conservation concern in the area (see Section 2.5 for errors of omission and commission from the draft covered species list, apparently resulting from using CNDDB to generate the list). CNDDB prioritizes species that are considered of conservation concern, but such lists change over time and CNDDB does not provide comprehensive coverage. Numerous rare and sensitive taxa are not included in CNDDB or have very few observations in the database—for example, in the case where a species was only recently added to a conservation concern list. In addition, CNDDB data are processed and uploaded at irregular intervals, with emphasis placed on different geographic regions of the state in different years. Perhaps most important, many of the sensitive

[11] REAT is the Renewable Energy Action Team, with representatives from US Fish and Wildlife Service, California Department of Fish and Game, California Energy Comission, Bureau of Land Management, and the California Natural Resources Agency.

Public Draft

taxa within the DRECP region are *subspecies* rather than full species, and data that do not consistently differentiate subspecies should not be used if one cannot determine whether a species record represents a relatively common or rare subspecies. Finally, great care should be taken in relying on any locality data that are not supported by vouchered specimens residing in a repository (herbarium or museum collection) upon which the identification can be verified. Taxonomy changes and uncertainties in identifications made by different observers vary too substantially to base important decisions on non-vouchered records.

Because of these concerns, CNDDB data, or any similar locality data, are best used as inputs to objective and appropriate modeling algorithms that can be used to project likely species distributions over unsurveyed areas (see Section 3.4), or to help verify or supplement other objective depictions of species distributions, rather than as primary predictors of species distribution and especially of species absence. *In the absence of appropriate, spatially explicit models or maps of species distributions, use "no regrets" approaches that site developments in areas already irreversibly converted by previous disturbance, and site conservation actions in areas already known to be important for sustaining covered species and communities, as detailed below.*

Inappropriate use of species range maps. Use of species range maps from the California Wildlife Habitat Relationships (CWHR) program suffers from similar problems as use of CNDDB data. Although the current protocols for CWHR range map revisions (Hooper et al. 2009, unpublished) are technically sound, most CWHR range maps have not been updated based on these protocols, and many are coarse in resolution and out of date. In many cases they have not been updated to reflect recent taxonomic changes. Moreover, to our knowledge CWHR range maps exist only for full species, not for subspecies. Overlaying species range maps to identify "hotspots" of sensitive species occurrences can therefore be highly misleading. For example, although the round-tailed ground squirrel, little pocket mouse, and Merriam's kangaroo rat are all very widespread species (see Section 2.5), their rare, endemic, and listed subspecies are very narrowly distributed; thus, use of the species range maps provides a distorted picture of areas most important for conserving sensitive taxa. *If GIS overlay methods are to be used to help identify areas of high or low conservation concern, great care should be taken to use range maps that accurately portray the ranges of the taxa of concern.*

Creating a single composite map of multiple environmental data layers without adequate analytical transparency. The advisors reviewed REAT maps showing "conservation opportunity areas" described as supporting "key populations or connections between key populations." The potential value or application of these maps is not clear without differentiating the various species, populations, or connections comprising it, and without explaining the methods used to produce the composite. Moreover, it is impossible to compare differing biological values or constraints on different parts of the map, which is essential to insightful prioritizing or phasing of conservation actions. Future maps should clearly differentiate, for example, existing reserve areas, unconserved areas, modeled habitat connectivity areas, species' ranges, and other important inputs to inform decision-making. If a single summary or composite map is desired for simplicity (e.g., for public outreach), the individual data layers (and how they were derived and treated in the composite) should be made available, and the compositing criteria and methods clearly articulated. *It is critical that all analyses and decision-making processes be as transparent and understandable as possible.*

4.2 Reserve Design Process

Reserves (otherwise known as protected areas, conservation areas, preserves, etc.) have been a cornerstone of conservation for centuries (Grove 1992). There has been a recent shift in perspective toward viewing landscapes as wholes in conservation planning, with increased attention to the contributions to conservation from the landscape matrix (i.e., mixed-use areas), rather than solely from reserves. Nevertheless, areas protected from intensive human use remain fundamental to conservation planning, because many species, communities, and processes are sensitive to human activity (Noss et al. 1999).

Principles for conservation planning and reserve design emerged as empirical generalizations based on case studies such as conservation of the northern spotted owl (Wilcove and Murphy 1991) and the southern California coastal sage scrub (Noss et al. 1997). These principles have been bolstered and refined over time with experience in diverse settings and planning contexts worldwide. The advent of systematic conservation planning and the increased use of sophisticated site-selection algorithms and spatially explicit habitat and population models (Margules and Pressey 2000, Carroll et al. 2003, Moilanen et al. 2009, Spencer et al. In Press) has made conservation planning more rigorous and quantitative, but sometimes at the cost of making conservation plans less comprehendible to land-use planners, decision-makers, and the general public, and often through a protracted process that defeats the original proactive intent.

For the DRECP *we recommend a phased conservation planning process, which takes full advantage of the considerable conservation and recovery plans already available for the region.* This phased approach will allow planners to make immediate "no regrets" decisions on important areas to conserve, areas where renewable energy projects can be sited, and methods for mitigating adverse effects of development—while at the same time performing additional conservation planning analyses to fill gaps in understanding and guide more difficult decisions. These analyses should be performed using a fully transparent process that incorporates empirical design principles and expert guidance. In other words, *the plan should be developed in an incremental, adaptive-management framework (as detailed in Section 6), evolving over time, both before and during implementation, as new information becomes available to fill our knowledge gaps.* Thus, some development and conservation can proceed as the planning process develops, guided at least in part by sophisticated modeling to help verify and refine what is already known. We offer the following principles as guidance for a comprehensive and systematic approach to planning a reserve network for DRECP.

4.2.1 Make Use of Existing Planning Documents

Conservation planning rarely happens in a vacuum, and DRECP has the benefit of numerous existing, science-based plans and analyses to use as a foundation. *We recommend that DRECP implement and improve on conservation actions identified by existing conservation and recovery plans in the planning area, beginning as soon as possible.* Considerable scientific input has already been applied in delineating important conservation areas and designing specific conservation and mitigation actions to preserve and recover sensitive desert species and communities in such documents as the Western Mojave Plan, the Northern and Eastern Colorado Desert Coordinated Management Plan, the Desert Tortoise Recovery Plan, the CalPIF Desert

Public Draft

Bird Conservation Plan, and ecoregional assessments prepared by The Nature Conservancy and other NGOs (see Appendix G for additional documents pertinent to conservation planning in California deserts). However, few of these conservation actions have actually been implemented, in large part due to lack of sufficient funding and staffing at the responsible agencies (Bunn et al. 2007). *Mitigation for renewable energy developments should be used to help rectify this situation by providing funding to implement appropriate conservation and recovery actions identified in existing plans, and to improve these plans over time via the DRECP Adaptive Management and Monitoring Program.*

In addition to plans prepared by government agencies, The Nature Conservancy, SCWildlands, Conservation Biology Institute, PRBO Conservation Science, and other research and planning NGOs have been developing maps and plans for conserving desert resources in recent years, using many of the types of sophisticated GIS models and decision-support tools recommended in this document. Although the science advisors have not comprehensively reviewed this body of work or specifically compared and contrasted their approaches with our recommendations, we believe such assessments are valuable references to build on for identifying DRECP conservation areas and actions. Rather than re-invent wheels, *DRECP should carefully review all such existing conservation assessments and plans and prioritize and phase implementation of the most useful and scientifically justified actions they recommend*. This review should consider our recommendations as general guidance, and should involve adequate scientific oversight and peer review of important documents or decisions.

4.2.2 Subdivide the Planning Area and Scale Each Task Appropriately

As detailed in Section 2.2, *we recommend dividing the planning area into several regions or planning units that are both ecologically relevant and potentially useful for dealing with the likely clustering of renewable energy developments* in different regions. Importantly, however, while planning subdivisions may be convenient and scientifically defensible across numerous planning tasks and analyses, they should not be universally applied to all species, communities, or analyses of interest (i.e., *don't assume "one-size-fits-all"*). Some analyses may need to be done at the scale of the entire DRECP area, others at more local or regional scales. If planning subdivisions are developed, consider whether they are appropriate for each analytical task, or whether combining, merging, or further subdividing the units is justified for any particular map, model, or analysis.

For some species, subregions might be best defined based on the species' demographic and genetic population structure across the planning region. For example, the desert tortoise recovery units, which are based on core tortoise population areas and genetic differences among them, may be most appropriate to use for that species. However, for most DRECP communities and species, subdivisions based on Ecological Sections and Subsections (Miles et al. 1998; http://www.fs.fed.us/r5/projects/ecoregions/toc.htm) or the subdivisions delineated by Webb et al. (2009a) for the Mojave Desert (see section 2.2) should suffice for ensuring adequate representation of biogeographic variability across the planning area.

Representation goals (defined in Section 4.2.3, below) *for each covered species and community should be established for each subregion, as well as for the entire DRECP area, to ensure*

adequate representation of biogeographic, genetic, and population variability across the plan area. At the community level, for example, a vegetation type might be well distributed throughout the planning area, but with considerable variation in species composition, climate, and habitat structure among subregions. Consequently, protecting examples of a vegetation type in certain subregions but not others will not capture this range of variation and may not allow for adequate adaptation to climate change. At the species level, a species that is distributed throughout much of the planning region, but in separate populations that vary in size or other characteristics, might be most efficiently conserved in a portion of the plan area supporting the largest and most intact population; however, other populations might be genetically distinct, provide insurance against diseases or catastrophes, be important functional components of a regional metapopulation, or turn out to be the most viable populations under changed climatic conditions.

4.2.3 Identify Areas Important to Conservation, and Areas *Not* Important to Conservation

The conventional approach in modern conservation planning is to conduct a top-down analysis of the planning region to identify and prioritize the most important areas to conserve. This approach is often guided by *representation goals*—or proportions of particular resource types (e.g., community types) to be conserved within a reserve network. The approach is intended to assure that all species, communities, and other features of interest are sufficiently represented in reserve areas to assure their viability. The advisors recommend combining this approach (detailed in the next section, 4.2.4) with an additional "bottom-up" approach of quickly identifying those areas that are demonstrably ***not*** important to achieving conservation goals—i.e., areas that due to previous disturbance are irreversibly converted from potential to support covered species, communities, or important ecological processes (such as wildlife movements). This will allow for the near-term siting of renewable energy developments in areas unlikely to contribute to the conservation of covered species or communities while planning of a more comprehensive, top-down reserve network can proceed. However, we urge diligent application of the Precautionary Principle in identifying such "no-regrets" areas for near-term development. The only areas likely to be unimportant for conservation are areas that have had native vegetation at least partly removed and the soil surface broken (e.g., by grading, grubbing, or tilling) that are also in locations unlikely to contribute to reserve viability or wildlife movement potential. We recommend that the DRECP planners map out areas of current and historical disturbance, verified by field surveys *and compared with existing reserve and linkage maps,* to make this assessment.

4.2.4 Apply Site-Selection Algorithms Wisely

Objective s*ite-selection algorithms* are useful in the top-down reserve selection process because, when used properly, they assure adequate representation of all features in a cost-efficient manner and because they allow transparent development and application of *a priori* representation goals by plan participants and stakeholders. Marxan (Possingham et al. 2000; http://www.uq.edu.au/marxan/index.html) and Zonation (Moilanen et al. 2005; http://www.helsinki.fi/bioscience/consplan/software/Zonation/index.html) are two algorithms that are widely used and have proven useful in diverse planning contexts. During the run of the Marxan algorithm, an initial portfolio of planning units is selected and the total cost calculated.

Planning units are then added and removed and the total cost re-evaluated through multiple iterations in an attempt to improve the total cost and efficiency of the portfolio for the selected conservation targets. The Zonation algorithm starts from the full landscape, and then iteratively discards locations (grid cells) of lowest value from the edge of the remaining area, thus maintaining a high degree of structural connectivity in the remaining habitat. Zonation works particularly well with grid-based inputs, especially those created by species distribution models. Moreover, instead of outputting the optimal set of sites for achieving targets, Zonation outputs the hierarchy of cell *removal* throughout the landscape and species loss curves, which can be useful in quickly identifying areas ***not*** important to conservation and therefore available for siting developments (see Section 4.2.3).

The selection of an algorithm and the associated parameter choices should be justified based on recent standards and peer reviewed literature, especially since this field of conservation biology is changing rapidly. We suggest that DRECP planners experiment with different algorithms before choosing one, and that they perform sensitivity analyses with each algorithm– e.g., vary the quantitative representation goals for various biodiversity features, clustering of planning units (i.e., the boundary length modifier in Marxan), etc., and observe the effect in terms of the pattern and overall area of selected sites in the design. Sensitivity analyses may also provide insight into the uncertainly associated with the reserve selection algorithm and output scenario. The specifications of the parameter settings within an algorithm should be well-documented and justified. In general, we suggest that site-selection algorithms are useful for defining the 'skeleton' of a reserve design, to which planners must apply expert opinion to add the 'flesh.' For example, site-selection algorithms often do not adequately account for connectivity between selected reserve sites, and habitat connectivity areas need to be added to the map.

Regardless of the selection algorithm used, usually some additional analysis is needed to prioritize sites for protection. This is often done by combining two criteria: irreplaceability (or biological value) and vulnerability (or threat) (Margules and Pressey 2000). Irreplaceability is a measure of the relative biological value and distinctiveness of a site. Sites supporting endemic species that occur nowhere else are irreplaceable relative to sites that contain only common or widespread species, for example. At the species level, a site with a high population growth rate, which serves as source population in a regional metapopulation, is irreplaceable; a sink population (where deaths exceed births) is generally not. However, when viewed at a broader spatial or temporal scale, sink populations may play important roles in metapopulation persistence, for example by providing connectivity or "stepping stones" between source populations or by increasing overall metapopulation size and genetic diversity. Also, populations that are sinks in most years may occasionally be sources, therefore enhancing the viability of metapopulation (e.g., Murphy 2002).

Vulnerability at the species level can be measured as the predicted decline in demographic value (e.g., population growth rate) over a period of time if development or other habitat degradation occurs (Carroll et al. 2003). Figure 4, from a study of the Greater Yellowstone Ecosystem, shows how sites might be ranked for conservation priority in terms of their irreplaceability and vulnerability. Sites in quadrant 1 are considered of highest priority for immediate action. However, in the long-term, sites in quadrant 2, being equally irreplaceable on average, are just as

Public Draft

important to protect – and are often more intact because they are generally more remote from human population centers (Noss et al. 2002).

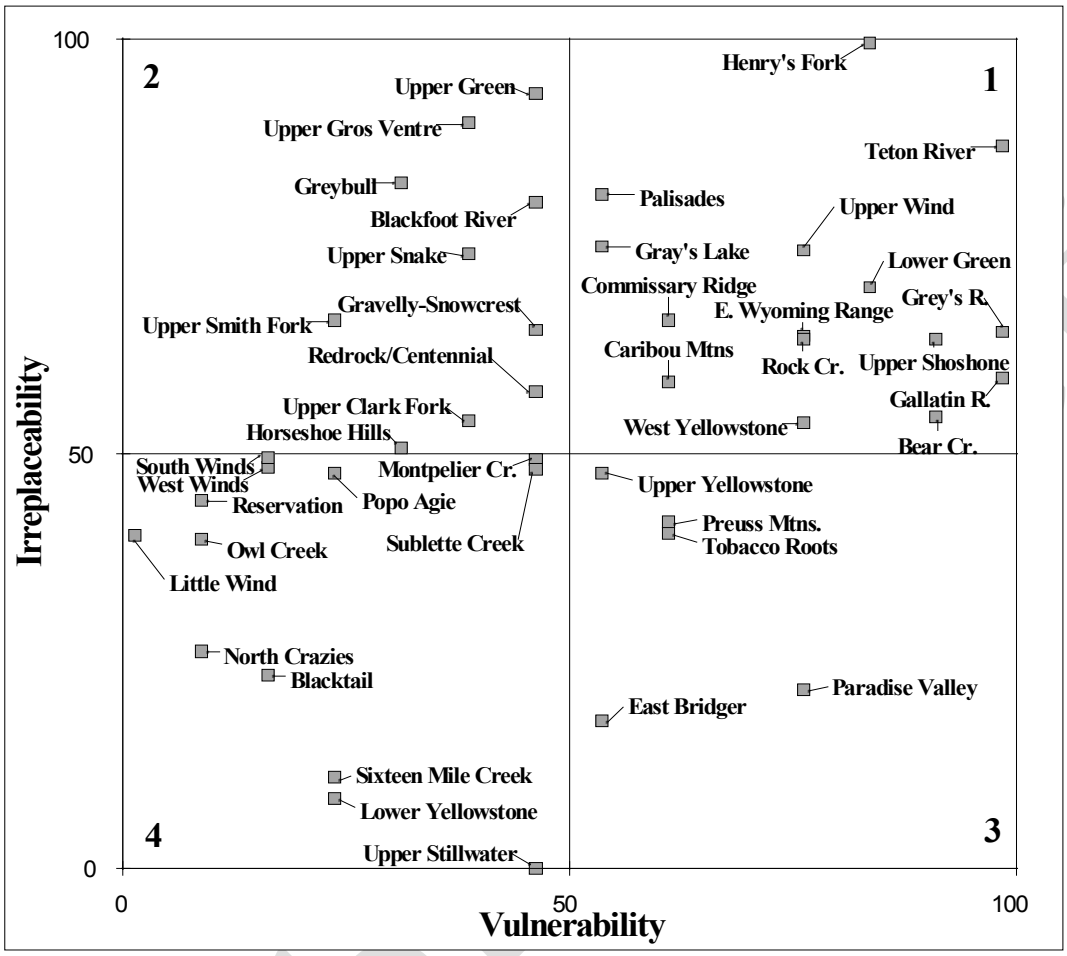

Figure 4. Example of site-specific conservation ranking based on irreplaceability and vulnerability scores. Sites in Quadrant 1 are highest priority for conservation.

Prioritization schemes are most useful in cases where scheduling issues exist – i.e., when it is not possible to protect all important sites at once. In such cases it is urgent to protect the high-value sites that are most threatened. In some conservation plans, including NCCPs, it is possible (at least in principle) to protect most or all biologically valuable sites at once, so such prioritization may not be needed. Nevertheless, if any delays in implementing a plan are anticipated, prioritization should be pursued.

In most conservation plans that apply site-selection algorithms, existing protected areas are "locked into" any conservation solution so that new reserves will add to the existing system rather than replace it. Hence, we recommend that top-down conservation planning for the DRECP start with the existing system of reserves (all categories) and build on it by adding new reserves, buffers, and connectivity. Importantly, the design must be based, to a large extent, on existing distributions of species, communities, and other features. However, it must also be able to accommodate shifts in species distributions with expected climate change. Hence, reserve system should protect a full range of enduring features and physical and ecological gradients

(Section 2.9) within contiguous and interconnected areas. Such a reserve system will provide species maximum opportunities to shift their distributions over time.

We suggest that the following elements are essential conservation targets, for which high representation goals should be established (i.e., approaching 100% in some cases):

- Unique Plant Assemblages as identified in Section 2.4.1.
- Special Features, as identified in Section 2.7.
- Areas of known importance to key covered or planning species, including at least the following:
  - desert tortoise critical habitat
  - bighorn populations and linkages
  - "core populations" and hypothesized linkages for Mohave ground squirrel
  - populations of species that are endemic or near-endemic (e.g., over 75% of total distribution) to the planning region
  - known habitat or populations of other species that are determined to be at high risk of extinction within the planning region
- Linkages between core habitat areas identified by any of the following: the California Desert Connectivity Project (Penrod et al., in preparation), South Coast Missing Linkages Project (Beier et al. 2006, South Coast Wildlands 2008) and California Essential Habitat Connectivity Project (Spencer et al. 2010).
- Habitat predicted to be essential to accommodate distributional shifts, in response to climate change, as predicted based on existing (e.g., Wiens et al. 2009) or future models.
- Areas important to maintaining dynamic geological processes, including eolian sand sources, wind corridors, and settling areas.
- Hydrologically important areas (e.g., washes, groundwater recharge areas, springs, seeps, etc.), including first- through fourth-order washes and washlets.

Regardless of the precise inputs, goals, and algorithms used, site-selection algorithms must be applied in a transparent and easily understandable manner. Use of algorithms must be augmented by attention to reserve design principles, and expert knowledge on species life histories, ecological processes, and other factors that determine viability of species and sustainability of ecosystem functions.

4.2.5 Use Planning Species and Other Key Surrogates to Derive Specific Design Standards

Many conservation planning efforts have applied general rules or principles (e.g., "bigger is better," "connected is better than unconnected," "corridors should be wide rather than narrow") that are difficult to apply in practice because they lack specificity. Only through intelligent consideration of the life histories of particular species, the distribution of physical environmental features, and the operation of key natural processes can conservation plans move beyond simple

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generalizations. We recommend the use of focal or planning species (see section 2.6, above) to help derive more realistic and specific reserve design standards. In addition, natural processes, such as wind, hydrology, and fire (in areas with historic fire regimes) can be useful as surrogates for reserve design, with the goal being to maintain a spatial configuration of habitats that allows for natural operation of these processes.

4.2.6 Provide Large, Well Distributed Core Areas, but Don't Ignore Important Small Areas

Arguments in the academic literature about whether it is better to have fewer large reserves or more small reserves have died down with the recognition that the question is a red herring–it depends on the species and other case-specific details, and almost never will a conservation planner have to decide between one or the other (Soulé and Simberloff 1986, Noss and Cooperrider 1994). All else being equal, reserves should be as large as possible, because larger reserves have more resources, higher species richness, and larger populations that are less vulnerable to extinction; larger reserves are also less vulnerable to edge effects and other threats that cross reserve boundaries. However, many natural features (e.g., a spring or isolated dune) are small but nevertheless irreplaceable. They should be buffered, when possible (see below), but certainly not ignored simply because they are small.

An important consideration in determining necessary reserve size is the area requirements of the species of conservation interest that inhabit the area. Different species have different area requirements, with large-bodied carnivores generally requiring the largest areas (Woodroffe and Ginsberg 1998). We recommend that planners for the DRECP identify the most area-limited focal species (see Section 2.6) for each major vegetation type as a guide, the objective being to create reserves large and/or connected enough (see below) to maintain viable populations of all of those species.

4.2.7 Buffer Reserves with Compatible Land Use

The concept of surrounding reserves with buffer zones of appropriate, low-intensity land use goes back at least to the seminal work of ecologist Victor Shelford in the 1920s through 1940s (Croker 1991) and later incorporated into the biosphere model (UNESCO 1974) and adapted to reserve design in diverse landscapes (Harris 1984, Noss and Harris 1986, Noss 1987). Although well accepted by conservation biologists, the buffer zone idea has not always been politically palatable (i.e., it is seen by some as a sneak attempt to enlarge reserves; Noss, pers. obs.), nor have established buffer zones been easy to defend. Nevertheless, the concept remains valid, and establishment of the buffer zones is even more defensible and urgent during the present period of rapid climate change and shifting species distributions. The details of buffer zones (e.g., how wide they need to be, what land uses are permissible, are they considered part of a reserve or a separate, outside zone) are again highly case specific, depending on the particular species and resources that are expected to benefit from buffering, the size and habitat quality of the core area that is being buffered, the nature of the surrounding matrix, land ownership and land use issues, and other factors. There may be no substitute for highly skilled expert opinion in determining buffer zone requirements, although a well-designed adaptive monitoring program (Section 6) should supply empirical data over time to better justify and refine buffer requirements.

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4.2.8 Connect Reserve Areas and Provide for Wildlife Movement

Habitat fragmentation and disruption of wildlife movements are great threats to covered species. Connectivity needs are species- and landscape-specific, and approaches based on the requirements of a wide range of focal species are generally most defensible (Beier et al. 2006, 2008; Spencer et al. 2010). Although it is important to select and plan for the needs of those focal species that are most sensitive to habitat fragmentation and movement barriers, it is also important to consider the different movement modes and constraints of diverse taxa. Although large carnivores are often assumed to be ideal focal species for designing corridors, corridors designed for them may not provide adequate connectivity for other wildlife (Beier et al. 2009). Some species that are not particularly wide-ranging (e.g., many reptiles or small mammals) are appropriate focal species for designing linkages, in part because they may be more likely than larger animals to avoid roads or be killed on roads. And, although birds are often neglected in connectivity plans because most can fly over unsuitable areas, some birds are highly susceptible to fragmentation effects and are useful for connectivity planning—such as roadrunners, quail, or other birds that mostly travel on the ground or fly only short distances.

Rigorous tools are now available for designing, assessing, and comparing linkage designs and movement corridors (Beier et al. 2008, McRae and Beier 2007, McRae et al. 2008, Spencer et al. 2010) and for incorporating uncertainty into corridor designs (Beier et al. 2009). However, rather than starting from scratch, *we recommend that DRECP review, incorporate, and build on previous connectivity work in the planning area. Specifically, the following references should be consulted by DRECP, and their results used to help with DRECP reserve design:*

- California Essential Habitat Connectivity Project (CEHC; Spencer et al. 2010),
- California Desert Connectivity Project (Penrod et al., in preparation),
- South Coast Missing Linkages Project (SCML; Beier et al. 2006, South Coast Wildlands 2008),
- Likely bighorn sheep movement corridors (Epps et al. 2007).

The California Desert Connectivity Project (Penrod et al., in preparation) provides the most comprehensive and detailed connectivity analysis available for the DRECP planning area. Results of this project—including least-cost corridor models for diverse focal species and detailed, multi-species linkage designs using the methods described in Beier et al. (2006)—should be incorporated into the DRECP reserve design following peer review and refinement, as needed. The goals of the Desert Connectivity project are to identify the most important areas in need of conservation and management to sustain and improve habitat connectivity and movement potential between large core areas (mostly large habitat areas on public lands) throughout California's deserts. The process included using an expert workshop—attended by numerous scientists, conservationists, and land managers from governmental and nongovernmental organizations—to identify large habitat areas in California's deserts that are most in need of connectivity and to select diverse focal species whose movement and habitat needs should be accommodated by landscape linkages. The experts identified 47 important linkage areas, which were objectively rated using a consensus scoring procedure to rank their biological irreplaceability (value) and the relative degree of threat to their functional connectivity

(see section 4.2.4). This ranking process was used to prioritize 23 linkage areas for detailed modeling and linkage design, based on the habitat and movement needs of 48 focal species (10 reptiles and amphibians, 13 mammals, 11 birds, 9 plants, and 5 invertebrates).

Least-cost corridor models (Beier et al. 2006, 2008) were then developed between habitat and population core areas for each species. These single-species linkages were then composited (using a GIS "union" function), further assessed for their ability to support populations and movements of focal species, and buffered (following methods described by Beier et al. 2006) to develop 23 robust, multi-species linkage designs intended to ensure functional connectivity for all focal species. Detailed management and monitoring recommendations are being developed for each linkage area, which includes identifying specific locations and design criteria for wildlife crossing improvements, such as road-crossing structures (e.g., wildlife underpasses or overpasses), wildlife fencing, and other measures to reduce roadkill and improve population connectivity.

The South Coast Missing Linkages (SCML) project (Beier et al. 2006, South Coast Wildlands (2008) preceded the Desert Connectivity Project (Penrod et al. in preparation), which expanded the geographic area from California's South Coast Ecoregion across California's desert ecoregions. SCML developed several linkage designs that connected portions of the South Coast Ecoregion with the Mojave and Sonoran Desert Ecoregions, and thus several linkage designs prepared for SCML are partly within the DRECP plan area and should be incorporated (see Appendix G for hyperlinks to appropriate SCML linkage reports). The Desert Connectivity Project was designed to be complementary to SCML, using similar analytical tools; *and together all existing linkage designs from these two projects that are in or partly within the DRECP area should be incorporated into the DRECP conservation design*.

The California Essential Habitat Connectivity Project (CEHC; Spencer et al. 2010) was coarser in scale than the Desert Connectivity Project or SCML, and did not use focal species to identify areas needing connection (instead, it used indices of environmental integrity and other biological inputs to identify large "Natural Landscape Blocks" and "Essential Connectivity Areas" throughout California). We do not recommend relying on maps from CEHC as *primary* inputs for site-specific reserve design in DRECP—due to coarse resolution, data constraints, and resulting errors of omission from the Natural Landscape Blocks and Essential Connectivity Areas, *especially in the deserts* (Spencer et al. 2010, page 41). The finer-resolution, focal-species maps produced by Penrod et al. (in preparation) and South Coast Wildlands (2008) are more defensible for DRECP reserve-design purposes. Nevertheless, we recommend considering the Natural Landscape Blocks and Essential Connectivity Areas identified by the CEHC as additional important areas to conserve, particularly where they lie outside of conservation priority areas not already conserved or mapped by other efforts.

More importantly, CEHC is an important source of information and guidance for how to maintain and improve habitat connectivity, wildlife movement, and adaptation to climate change. It provides a comprehensive and stepwise review of how to develop detailed regional and local linkage plans, wildlife crossing structures, and other conservation actions to counter fragmentation and climate change effects on ecological communities and species. It also

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addresses methods for incorporating climate change adaptation into linkage designs, such as the land-facets approach of Beier and Brost (2010).

Additional Linkage Planning. Although the existing linkage plans discussed above provide a solid starting point for addressing habitat connectivity in DRECP, we emphasize that *these efforts should not be used uncritically, but should be reviewed, refined, and built upon as needed to meet plan goals*. Additional linkage designs, for additional focal species or areas of concern, may be required to supplement existing designs. Spencer et al. (2010) detail step-by-step processes for preparing such designs. In addition, they stress the importance of *recognizing all riparian areas and washes as important linkage features* (which is especially true in light of climate change: Seavy et al. 2009) regardless of their location inside or outside of natural habitat blocks or reserve areas.

4.3 Siting, Configuring, and Mitigating Renewable Energy Developments

Renewable energy developments may contribute to loss, fragmentation, and deterioration of plant and animal populations and habitats; changes in above and below ground hydrology; and increases in roads, vehicular traffic, subsidized predators, light pollution, dust, and human populations locally and regionally. The extent of the negative impacts depends on the type, location and size of the development, as well as how the energy is transmitted off-site. Some negative impacts from development will spill over onto adjacent lands and may have impacts far beyond the footprint of the developed site. Also, as introduced in Section 2.10, different types of renewable energy development will have different sorts of impacts, and therefore different siting and mitigation guidelines.

4.3.1 General Guidance for All Covered Actions

In general, the advisors recommend adhering to the strict sequencing of "avoid, minimize, and mitigate" for impacts to biological resources and ecosystem processes. Preference should always be given to avoiding impacts to undisturbed habitat areas and siting developments on already disturbed areas, so long as siting a development in a previously disturbed area won't disrupt important ecosystem processes, such as wildlife movements, water flows, or eolian sand transport and dune dynamics. Where strict avoidance of new disturbance is not possible, project siting and design should strive to minimize impacts to native vegetation, undisturbed soils, wildlife movement, or other important resources and processes. Finally, unavoidable impacts should be mitigated by appropriate actions.

The following recommendations apply to all covered actions:

- Site developments to the greatest extent possible on already disturbed lands (where vegetation has been altered and soil surface broken or disturbed), such as fallow agricultural fields, brownfield sites, industrial sites, and scattered private and public lands within and adjacent to cities and towns. Such sites are readily available throughout the Mojave and western Sonoran deserts. We also of course endorse "roof-top" or distributed solar development in urban areas to maximize power production from sites with little or no biological value.

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- Site developments as close as possible to and use existing transmission line corridors and rights-of-way as a high priority. "Bundle" or co-locate linear facilities immediately adjacent and parallel to one another to avoid new fragmenting effects. Be aware in some cases that this make an existing partial barrier to wildlife movement even worse, but in most cases this is likely better than creating new fragmentation. Mitigate adverse effects of linear features on wildlife movement by creating safe crossing areas through existing, new, or bundled groups of linear features
- Avoid any developments within critical habitats for federal and state-listed threatened and endangered species; candidate species for federal or state-listing; sensitive habitats, core areas, and important linkages, migration corridors, or habitat connectivity areas (Spencer et al. 2010, South Coast Wildlands 2008, Penrod et al. in preparation, Epps 2007); or in designated Natural Areas, Research Natural Areas, Areas of Critical Environmental Concern, and Wilderness.
- Minimize the impact footprint of a development to the maximum extent possible, recognizing that the impact footprint may be larger than the actual development or construction footprint. For example, wind energy projects are often characterized as having relatively small project footprints, because the turbines themselves disturb small areas of ground. However, in assessing ecological footprints it is important to include all components necessary for a viable project (e.g., access roads and transmission lines). Include offsite effects, such as interruption of sheet flows that support downslope vegetation or interruption of blowing sands that support active dune systems.
- Avoid contributing to habitat fragmentation adjacent to or in the proximity of reserve areas or important habitat areas, including National Parks, ACECs, Wilderness Areas, etc. In many cases, the original boundaries of sensitive environmental areas were based on such factors as land ownership and politics, rather than on principles of reserve design or on maintaining viability of an ecosystem. Siting a renewable energy project with associated transmission lines adjacent to a protected area has high potential for fragmenting the landscape.
- Fence highways and roads providing access to renewable energy sites with appropriate animal-proof fencing to reduce illegal collection and road kills of wildlife, and to reduce food sources of subsidized predators. Special wildlife crossing structures (e.g., underpasses and overpasses that facilitate movements of animals) may be necessary for sites that are not located in or adjacent to towns and cities. The type of wildlife crossing and fence will depend on the focal species of concern. See Boarman (1995) and Boarman et al. (1997) for effectiveness of fences and culverts for protecting desert tortoises along highways, and Spencer et al. (2010) and references therein for general guidance for siting and designing wildlife crossing structures.
- Reduce light pollution by minimizing the number and intensity of lighting units and directing any light away from habitat areas.
- Fence artificial water sources, such as evaporation ponds, and cover them to reduce subsidies to predators (e.g., coyotes and ravens) and to prevent birds, bats, and other animals from becoming entangled, ill, or otherwise harmed by the fluids.
- Minimize dust and sand generated by construction and by travel on dirt roads. Avoid producing deposits and accumulation of eolian sands adjacent to and downwind from the site,

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because such surficial materials provide seed beds for alien plants and cause habitat deterioration.

- Restrict temporary construction disturbances, such as lay-downs and access routes, to existing roads and disturbed areas.
- Develop and implement a long-term program to eliminate alien annual plants in and near project sites, access roads, and transmission line corridors and other areas used to transmit power.
- Develop and implement a long-term program to prevent trash and food scraps associated with the facility, contractors, and employees from becoming distributed beyond closed receptacles at the site. Trash must not be allowed to blow out of or away from the site and access roads and become distributed on the landscape. Trash has a negative effect on wildlife and may draw in undesirable species or aggregate species in disproportionate numbers (such as ravens). Collect any trash that blows off-site.
- Evaluate growth-inducing and cumulative impacts as part of environmental analyses, minimization and mitigation measures, and permit requirements.

4.3.2 Linear Infrastructure

- Minimize the total length of new (and temporary) roads, transmission lines, or other linear structures to the degree possible by siting energy projects near existing infrastructure, and avoid bisecting undisturbed desert habitats or crossing preserve areas. "Bundle" or co-locate new roads and transmission lines within existing easements and transmission line corridors, and retrofit existing transmission lines to carry additional electricity, or site new rights-of-way along other existing linear features, such as canals, roads, and aqueducts.
- Site, design, and construct appropriate crossing structures for wildlife across roads, canals, and other linear barriers or filters to wildlife movement. See Spencer et al. (2010, pages 141-146) and references therein (especially Meese et al. 2009, Clevenger and Huijser 2009, and http://www.wildlifeandroads.org/) for detailed reviews of road mitigation measures and recommendations for siting, designing, and implementing crossing structures, fences, and related measures. In addition, see Brooks (1995, 2000), Boarman (1995), and Boarman et al. (1997) for information on the effectiveness of fencing and culverts as mitigation measures for desert reserves and desert tortoises.
- Where new or refurbished transmission lines cross desert habitats, evaluate whether undergrounding can be used to minimize impacts. Undergrounding may not be desirable, because this could alter hydrological or other overland flow processes. Conduct pilot tests with appropriate Before/After-Control/Impact (BACI) sampling designs (see Section 6.4) to compare the relative impacts of different transmission designs (e.g., elevated vs. undergrounded) on biological and geohydrological resources.
- Use deterrent devices to discourage perching by ravens and raptors (Slater and Smith 2010) on transmission lines, towers, or other structures.

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4.3.3 Solar Projects

The main impact of solar projects on biological resources is the direct removal, degradation, and fragmentation of habitat areas, although there are also concerns about indirect impacts and potential mortality of birds and insects from thermal concentrating facilities (Section 2.10.3).

- Site solar energy facilities on previously disturbed lands such as old or abandoned agricultural fields, areas scraped or bulldozed for development of tract housing, lands cleared of native vegetation and zoned for light industry, and lands within or on edges of cities, towns, and existing settlements on valley floors.
- Study the possibility of siting solar projects in long, narrow, linear arrays along existing roads (e.g., in interstate medians?), canals, or other linear features that already represent barriers to wildlife movement or major habitat fragmentation features. This will minimize new fragmentation effects. Mitigate the combined effect of any new developments and existing features with wildlife crossing features, including occasional wide gaps in developments, coupled with appropriate wildlife crossing structures (e.g., wildlife overpasses, underpasses, or bridges to accommodate road crossings) and appropriate wildlife fencing to funnel animals to the crossing location.
- If necessary, fence solar facilities with animal-proof exclusion fencing to protect against entrapment and mortalities, but mitigate for disruption of wildlife movement potential by improving wildlife crossing areas elsewhere (e.g., by providing road crossing structures for wildlife in other locations).
- Avoid siting on playas, playa margins, high-slope alluvial fans or bajadas, and old geologic surfaces armored with desert pavement because of the high potential for dust pollution and disruption of hydrological regimes. Site solar energy facilities on low-slope fan aprons out of eolian transport zones and preferably in previously disturbed landscapes.
- Avoid siting near habitats that concentrate birds and other desert wildlife, including all wetlands, major washes, oases, etc.
- Mitigate the confusing effects of polarized light reflections from solar panels on wildlife species that may mistake them for water bodies or that otherwise use polarized light as behavioral cues by experimenting with and applying cell borders or grids that break up the reflections, as described by Horvath et al. (2010).

4.3.4 Wind Projects

Although the direct impact footprint of wind turbines are relatively small, like all projects their ancillary features, including roads, transmission lines, etc., increase both the direct and indirect impacts. Wind turbines also can directly kill numerous birds and bats, which is one of the major concerns.

Fortunately, good guidance already exists for siting turbines and mitigating for and monitoring their effects. New federal guidelines for minimizing adverse effects of wind turbines on wildlife were recently released (too recent for review in this report) by the USFWS Wind Turbine Advisory Committee. In addition, the California Guidelines for Reducing Impacts to Birds and Bats from Wind Energy Development (CEC and CDFG 2007) provide relevant, science-based

Public Draft

guidance for siting of wind energy developments in California. They provide relevant guidance for pre-construction and operations monitoring of bat and bird activity levels, fatality monitoring during operations, siting recommendations at the facility and turbine level, and approaches to mitigation. The Guidelines were completed following a stakeholder process facilitated by CEC and CDFG and have been vetted by conservationists, developers, and other interested parties to arrive at a set of mutually acceptable standards. Although new information gathered during implementation of wind-energy developments should continue to improve on these guidelines, they provide the best available guidance on monitoring and mitigation and should be used by DRECP.

Especially important is a recommendation in the Guidelines to archive results of pre-construction and operations monitoring efforts in an accessible database. This recommendation applies to all proposed sites within the DRECP planning area, whether they become operational facilities or not. Over time, such a database has the potential to promote adaptive learning regarding the linkage between pre-construction surveys and fatality rates of bats and birds at operational facilities. In addition, it may help to suggest thresholds for what should be considered high levels of activity or sites which pose greatest risk to birds or bats.

As part of pre-construction monitoring for siting new or repowered turbines, study the flight and foraging behavior of condors and other raptors relative to terrain, wind, and other factors. Research has shown, for example that repowering older wind turbines in the Altamont Pass Wind Resource Area (central California) with fewer, taller turbines reduced mortality rates for large raptors like golden eagle and redtailed hawk, although it may have increased bat mortality rates (Smallwood and Karas 2009). Switching to single pole (as opposed to open lattice) tower structures, and sealing all openings that birds can enter or use for nesting, has reduced perching and nesting by birds on the towers, further reducing mortality rates. Avoiding the siting of turbines in ridge saddles or other terrain features that tend to concentrate flight paths can also reduce impacts (Smallwood et al. 2009).

Evaluate temporal avoidance to further minimize potential impacts at both the facility-and turbine-level (CEC and CDFG 2007) by defining when impacts occur, and under what environmental conditions (e.g., time of day, season, wind speed, and temperature). Intensive (e.g., daily) ground searches for bird and bat mortalities during selected periods could provide sufficient data resolution to evaluate these factors. Using this information, it is possible to fine-tune turbine operations to reduce mortalities. For example, recent research demonstrating that bat activity and fatalities were highest on nights with low to moderate wind speeds (Arnett 2005, Arnett et al. 2006, Weller 2008) has led to mitigation experiments where cut-in speeds of turbines have been raised to reduce bat fatalities. These mitigations have led to >50% reductions in bat fatalities with minimal changes to power output (Arnett et al. 2009, Baerwald et al. 2009).

4.3.5 Guidelines for Improving Effectiveness of Mitigation

Numerous mitigation actions to offset adverse development impacts to plants and animals have been tried, but the successes and failures of various approaches are poorly documented and few publications are available concerning the effectiveness of alternative mitigation measures for biological resources in the California deserts. Some information is available on the value of fenced and protected preserves (e.g., Brooks 1995, 2000). Data are also available on

Public Draft

effectiveness of highway fencing and use of culverts to protect desert tortoises (Boarman 1995, Boarman et al. 1997). However, much more needs to be done within a scientific framework on such topics as control of invasive and established alien plants, recovery of native annual and perennial vegetation after disturbance, and control of subsidized predators.

We recommend that *DRECP encourage and potentially fund a research project by an appropriate academic or research institution to review the history and effectiveness of various mitigation and conservation actions in California*. The objectives of the document should be to identify what works and what has not, to recommend possible solutions, and to advance the state-of-the art in mitigating and off-setting the effects of development, especially with regard to renewable energy projects. The compilers of this document should work with employees in state and federal agencies associated with protection and management of public and private lands, non-profit corporations involved in acquiring and protecting land and implementing mitigation measures, and law enforcement personnel actively engaged in protecting habitat and wildlife. This compilation should focus on what can be done to improve conservation and mitigation efforts. Some individuals may be reluctant to speak about failures. Nevertheless, failures should be identified and used as a means of improving the mitigation and compensation process.

One action that we generally do ***not*** endorse as mitigation *per se*—except perhaps under certain rare circumstances where scientific evidence suggests it may be warranted—is animal translocations out of proposed development areas into reserve areas. This is often done but rarely effective—a "feel-good" measure that has dubious ecological benefits and potential to do more harm than good. Although carefully designed translocations can be useful under certain circumstances—such as reintroducing a species to former areas of occupancy, given that the reason for their original extirpation has been rectified—simply moving animals from one area to another (likely already occupied) area is not recommended. In all cases, such extraordinary actions as translocations, reintroductions, or predator control should be treated as adaptive management experiments, with appropriate monitoring to ascertain their effectiveness and to maximize information gained from the experiment.

Public Draft

5 Additional Principles for Conserving Select Covered Species

Previous sections of this report provide comprehensive approaches for conserving covered species and communities via avoidance, minimization, and mitigation measures and a broad, landscape-level approach to designing a reserve network for desert biota. This section provides some additional information pertinent to conserving and managing particular species or groups of species, over and above recommendations in earlier sections. This information should be seen as supplemental to a comprehensive, multi-species, multi-community approach to conserving and managing a broad, landscape-level reserve network to sustain desert communities now and into the future.

- **Mohave Ground Squirrel.** We advise following recommendations currently being prepared by the Mohave Ground Squirrel Technical Advisory Group (MGS TAG), a long-standing committee of MGS technical experts from the private sector, academia, and land management and regulatory agencies. The TAG has drafted MGS conservation priorities based on recommendations made by Leitner (2008) and modified based on more recent information and expertise of TAG members. The document is currently in review by TAG members, with a goal of producing a final, consensus document as early as September, 2010 (S. Osborn, CDFG, MGS TAG Chair, personal communications). In the meantime, the DRECP advisors generally endorse the following recommendations from P. Leitner (2008, and personal communications) concerning conservation priorities for Mohave ground squirrel: (1) maintain connections between known population areas and avoid siting developments in known population areas or potential connectivity areas; (2) establish buffer zones of at least 5 miles (8 km) around four identified "core" population boundaries, avoid developments in these buffer zones, and manage them to protect colonizing juveniles; (3) acquire private inholdings within these delineated core populations; (4) restrict off-highway vehicle (OHV) use to designated routes within BLM lands in core areas; (5) conduct additional surveys to identify new population areas and improve understanding of potential connecting habitats. In general, the advisors do ***not*** recommend translocation or captive breeding as effective mitigation or conservation actions for Mohave ground squirrel (or most covered species). Natural history characteristics of MGS make them particularly poor candidates for translocation or captive breeding, and *in situ* habitat conservation and management is far superior to attempting to move animals to new locations or to bolster existing populations. If translocations are attempted, they must be treated as experiments, with intensive and long-term monitoring of populations to determine their effectiveness and improve scientific understanding of the species.

- **Desert Tortoise** (*Gopherus agassizii*). The advisors recommend that DRECP review and implement appropriate conservation, mitigation, and recovery actions outlined in the Desert Tortoise Recovery Plan. The desert tortoise is a widespread species (Nussear et al. 2009) whose numbers have declined for decades and continue to do so (USFWS 1994) due to a variety of anthropogenic activities (USFWS 1994, Tracy et al. 2004). Tortoise populations are susceptible to losses from disease (Jacobson et al. 1994, Homer et al. 1998, Brown et al.

Public Draft

1999, Christopher et al. 2003) drought (Berry et al. 2002, Longshore et al. 2003) and predation (Esque et al. *In Press*) and are slow to recover. Little empirical data are available about the dispersal and survival of young desert tortoises, although adult tortoise movements have been observed for decades. Desert tortoise home ranges are known to range from 4 to 40 ha or more, and movements of up to 20 km have been recorded. There is one published record of movements in excess of 30 km from the Sonoran Desert (Edwards et al. 2004). Thus relatively short dispersal distances coupled with long life-spans likely mean that isolation by distance is a primary mechanism for population differentiation (Murphy et al. 2007, Hagerty and Tracy 2010). Based on landscape genetics analyses, connectivity among desert tortoise populations has been primarily affected by mountain ranges and extremely low elevation valleys (Hagerty et al. *In Review*). Disturbances caused by linear features or activities that block landscape pinch points have "likely removed all possible paths among previously connected populations" (Hagerty and Tracy 2010). Connectivity among populations may also be affected by factors causing localized extinctions. As with the Mohave ground squirrel, the advisors do ***not*** recommend translocation of desert tortoise as effective mitigation or conservation action, in part because translocated tortoises suffer high mortality rates. We do endorse implementing roadside fencing to reduce roadkill and road undercrosses to improve population connectivity, as called for in the Desert Tortoise Recovery Plan.

- **Bats**. Basic conservation needs of bats are met by ensuring that roosts, foraging areas, and free water are maintained within a few km of one another. However species of bats differ in the types of structures used as roosts, types of habitat favored for foraging, and nightly distances travelled to reach foraging and drinking areas. Therefore, conservation and mitigation efforts must take care to ensure that proposed actions are species-specific and maintain viable juxtaposition between important resources. For instance, loss of cave roost habitat in one area cannot be mitigated via protection of rock face or tree roost habitat elsewhere, as it would be unlikely to be used by the affected species. Similarly, loss of roost habitat cannot be offset through provision of foraging habitat. The success even of in-kind (e.g., protection of foraging habitat to offset loss elsewhere) habitat substitution should be verified through an adaptive management process before it is widely implemented as a mitigation tool.

  In addition, bats must be able to move freely between seasonal habitats to reach mating and birthing areas. Evidence to date suggests that bats are most vulnerable to collision mortality with wind turbines during these seasonal movements (Arnett et al. 2008). These conclusions were based largely on impacts to tree roosting bats at latitudes further north than the DRECP planning area. However recent monitoring results at a wind energy facility within the DRECP planning area suggest that timing of impacts may be similar (e.g., during spring and fall migration periods) even if the species involved differ (Chatfield et al. 2009). Effective conservation of bats that migrate seasonally should ensure that steps are taken to minimize collision mortality at wind energy facilities.

Public Draft

6 Principles for Adaptive Management and Monitoring

Adaptive management is a systematic process of using advances in scientific knowledge to continually improve management practices by learning from outcomes of previous actions. An Adaptive Management and Monitoring Program is a mandatory component of an NCCP/HCP, and a carefully designed management and monitoring program is essential to success of any conservation plan. Often, however, this crucial component is addressed near the end of the planning process, almost as an afterthought once the conservation design and mitigation measures are established. We recommend an alternative strategy of developing key aspects of the Adaptive Management and Monitoring Program up front. In essence, *DRECP should be treated as a huge environmental experiment that should be developed and implemented incrementally in an adaptive management framework—with continuous monitoring and scientific evaluation to reduce uncertainties and improve plan actions over time*.

The advisors strongly recommend the following Principles to guide the statutorily required Adaptive Management and Monitoring Program (AMP), which we expand on in following sections:

- **Timing:** *Begin monitoring studies, and implementing adaptive management actions, immediately—during planning—to reduce uncertainties about plan outcomes and inform future plan decisions.*

- **Institutional structure:** *Develop a formal institutional structure that ensures strong, effective feedback from monitoring and research studies to plan decisions, and use this structure to continually improve all aspects of the plan over time, during both plan development and implementation.*

- **Hypothesis-based monitoring:** *Use conceptual and quantitative models that formalize understanding of the systems of interest to guide development and testing of hypotheses with monitoring studies.*

- **Appropriate monitoring design.** *Use robust statistical sampling designs for monitoring programs to maximize reliability of resulting data, including (1) Before/After-Control/Impact designs for new energy developments and (2) systematic surveys across the plan area to better establish landscape-scale baseline conditions.*

- **Focused research studies.** *Implement focused research studies to address uncertainties about how to sustain covered species and communities, such as landscape genetics and demographic studies to determine where conservation actions are most needed to sustain populations in the face of habitat fragmentation and climate change.*

Public Draft

6.1 Implement Monitoring and Adaptive Management Immediately

Typically, adaptive management and monitoring plans have been developed as final steps in NCCP and HCP planning, with monitoring recommendations developed almost as an afterthought once the conservation plan is drafted, or even after an implementing agreement has been signed (personal observations of advisors). Given uncertainties about the impacts of diverse renewable energy developments and associated infrastructure on covered species and communities, DRECP should reverse this typical approach by *immediately developing and implementing monitoring protocols and securing access to lands proposed for renewable energy development*. Researchers from governmental and nongovernmental research institutions *must have access to lands proposed for development before, during, and after construction and operation of energy developments and appurtenance structures.* Access prior to construction is necessary to characterize ecological baseline conditions in and near proposed developments and thus allow Before/After—Control/Impact (BACI) sampling designs (Green 1979). BACI designs allow for much stronger inference about impacts of developments on biological resources than the "after-the-fact" monitoring typically implemented by conservation plans. Results of these studies should be used to evaluate impacts during and after construction, and use the results to inform future developments. Moreover, the plan should initiate some systematic, landscape-scale sampling across the study area to better characterize baseline environmental conditions prior to implementation of large-scale energy developments and further climate change. These recommendations are expanded on in Section 6.4.

The advisors recommend obtaining additional scientific input as soon as possible to assess monitoring priorities, metrics, sampling designs, and related matters to implement at renewable energy projects permitted during within the coming months or year. Solid baseline sampling should occur as soon as possible, prior to any construction. Monitoring designs and protocols can be modified over time, but it is essential that initial sampling is robust to any likely changes to ensure comparable data over time. Detailed monitoring recommendations were beyond the scope of this science advisory report, given available time.

6.2 Framework and Institutional Structure

In concept, adaptive management is a strong and scientifically sound approach for improving plan actions by "learning as you implement." Unfortunately, however, it is almost never successfully applied due to weak institutional structures that fail to ensure that accumulating scientific information—whether data collected within the plan from monitoring studies, or information from outside the plan from research studies—is actually applied to refine actions and make the plan truly adaptive. Lack of clearly defined and enforced institutional processes, and a failure to assign, fund, and empower the necessary personnel, are typical. Independent Science Advisors for the Sacramento-San Joaquin Bay Delta Conservation Plan (BDCP) tackled this problem for that plan based on their collective experience with both failed and successful AMPs for other large, complex conservation and restoration plans around the world (Dahm et al. 2009). We urge DRECP to develop an institutional structure similar to that recommended by Dahm et al. (2009) as illustrated in Figure 5. This structure, along with more detailed guidance provided by Dahm et al. (2009) represents a vast improvement over the often vague and weak structure s that generally doom AMPs to fail. It should be adapted and refined as necessary to fit the

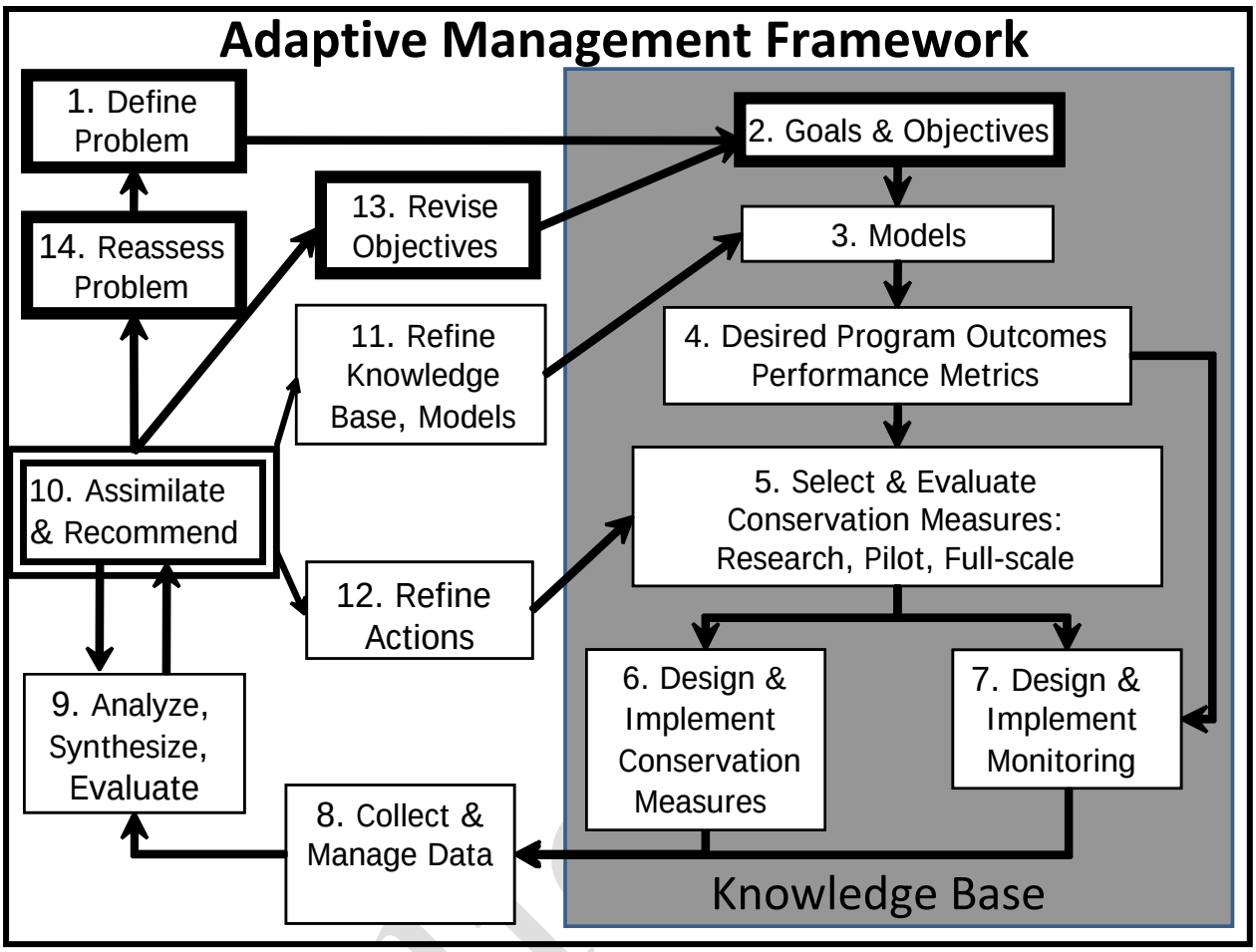

Figure 5. *A recommended AMP framework showing the flow of information and responsibilities of different entities.* The large shaded box underlying the right side of the figure represents the knowledge base for defining goals and objectives, designing predictive models, predicting outcomes, identifying performance metrics, and designing and implementing conservation measures and monitoring actions. Boxes framed with thin lines represent tasks performed by technical staff, such as scientists, land and water managers, and other analysts. Boxes framed with bold lines represent tasks performed by senior decision makers (i.e., policy makers and program managers who control program objectives and funding). The box framed with double lines (Box 10) represents a key step that is missing from most AMPs: Assimilate and Recommend. This task requires a body of skillful "polymaths" who understand both the technical and policy implications of the information passed along by technical staff (who analyze, synthesize, and evaluate monitoring and other data; Boxes 8 and 9). The task represented by Box 10 is to assimilate this diverse information, understand its consequences, and formulate recommendations to both the senior decision makers and the technical staff, such as revising plan objectives or conservation measures (Dahm et al. 2009).

particular needs of DRECP. For example, there should be a well-defined and enforced process for amending existing land-use and preserve management plans in California's deserts based on the DRECP conservation design and mitigation actions and the DRECP adaptive management and monitoring program. Likewise, there should be a clear and enforceable process for amending pre-existing permits for renewable energy developments based on new and emerging information concerning effective mitigation measures, new threats, and so on.

A key component of this recommended structure is represented by Box 10—assimilate information and formulate recommendations—which is where AMPs typically fail to adequately feed scientific information back into management and policy decisions. This function requires both policy and technical expertise, and is fundamental to the successful integration of accumulating knowledge and information into plan policies, such as revising goals and objectives, refining analytical models, or allocating funding. The link between the technical step of "Analyze, Synthesize, Evaluate" and the decision-making step of "Assimilate and Recommend" requires regular interaction and exchange of information between technical staff and decision makers.

Box 10 highlights the need for some highly skilled agent (person, team, office) to be assigned the responsibility for continually assimilating scientific information generated by investigations *both within and external to the adaptive management program* and transforming it into knowledge of the kind required for management actions. Boxes 11 through 14 indicate that such actions may include (1) refining a particular conservation measure, (2) refining the knowledge base and models of system behavior that are extracted from the knowledge base, (3) revising objectives of an entire conservation measure, and (4) reassessing whether the original target problem is solved, transformed, or still a problem. This last action may also be affected by external events such as changing societal preferences, newly recognized environmental threats, changes in available technology, or other changed or unforeseen circumstances. If new information suggests that conservation and mitigation actions codified in existing permits are ineffective, there should be a formal process for amending permits to rectify the situation.

The actions of the agent represented by Box 10 need to be carried out continually but on a range of time scales. For example, individual components of the knowledge base might be refined gradually and annually, whereas particular conservation measures might be refined only after a few years of project implementation. The entire problem might be re-assessed or re-visited once in a decade. The key principle, however, is that *the process of transferring and transforming the results of technical analyses into knowledge to support decisions cannot be taken for granted in the hope that it will occur in the absence of a body specifically charged with making it happen*. This function requires remarkably skillful people, who are truly inter-disciplinary ("polymaths"). Whatever their training, these individuals (or team of individuals) need to be comfortable with a wide range of technical information, as well as understand the functioning of government, law, economics, and the management of large projects.

6.3 Hypothesis-based Monitoring and Adaptive Management

Adaptive management is an active process in which new knowledge is gained and applied to managing natural resources (Holling 1978, Walters 1986). An overarching goal of adaptive management is to maintain optimally functioning ecosystems, with all their components (Noss

Public Draft

and Cooperrider 1994). This necessitates understanding the dynamics of populations, communities, and the resources they need (Landres et al. 1999). Hypotheses about processes and interactions that characterize sustainable populations, as well as proximate and ultimate stressors that affect them, need to be identified. When monitoring efforts determine those stressors are evident, management experiments are used to test various means of reducing the stressor's impact. These management experiments are coupled with focused monitoring to evaluate success (Morrison et al. 2001).

Traditional monitoring approaches that focus on quantifying population size, despite increasingly high levels of statistical rigor, have generally failed to address critical questions regarding factors that affect species and community dynamics (Barrows et al. 2005, Barrows and Allen 2007). Consequently, traditional monitoring often fails to provide clear direction to management. We propose a monitoring framework that is explicitly hypothesis-based, with species monitoring performed within a context of community, landscape, and ecosystem scales. This framework approach has been published (Atkinson et al. 2004, Barrows et al. 2005) and is being adopted as a guiding philosophy for many HCPs and NCCPs throughout California. The authors of the 1994 Desert Tortoise Recovery Plan also explicitly recommended hypothesis-based research and monitoring.

This approach builds on existing published research and employs primary data collection to build conceptual and quantitative models that link species population trajectories with community or ecosystem processes and conditions (conceptual model examples: Figures 6-7). The conceptual models are essentially a collection of hypotheses regarding the drivers and stressors of a species' or communities' temporal and spatial dynamics. It is an iterative process of designing a monitoring approach and collecting data to statistically evaluate models and hypothesis by partitioning large-scale models into discrete units. This breaks down the inherent complexity of ecological systems into manageable questions. A conceptual model leads to questions that can be answered with monitoring and addressed with adaptive management. Unless the model possesses that heuristic character it is of little value.

Figure 6 illustrates a conceptual model for desert tortoise. Monitoring long-lived species like desert tortoises is often problematic, because tortoise populations can remain stable for years even with little or no reproduction, so it may take many years to detect effects of stressors on tortoise populations. However, by examining the conceptual model we can develop a monitoring design that compares different metrics, such as the incidence of diseased adults or raven predation on hatchlings, with respect to road density or other measures of habitat fragmentation. If the numbers of predated hatchlings or diseased adults exceed that of unfragmented sites, management actions should strive to mitigate fragmentation effects. Similarly, invasive species such as Sahara mustard, *Brassica tournefortii*, are thought to be a source of stress for tortoises. A monitoring strategy to address this question might test such alternative hypotheses as: (1) is the mustard density associated with fragmentation or with loss of food?; or (2) are tortoises negatively impacted by the mustard, and if so how? This latter question could be addresses by comparing tortoise condition (perhaps by a morphometric-adjusted measure of the tortoises' weight, or incidence of disease) in mustard-infested versus mustard-free landscapes. If the tortoises' condition in the mustard areas is poorer than that on the native control sites, then adaptive management strategies to control the mustard should become a priority.

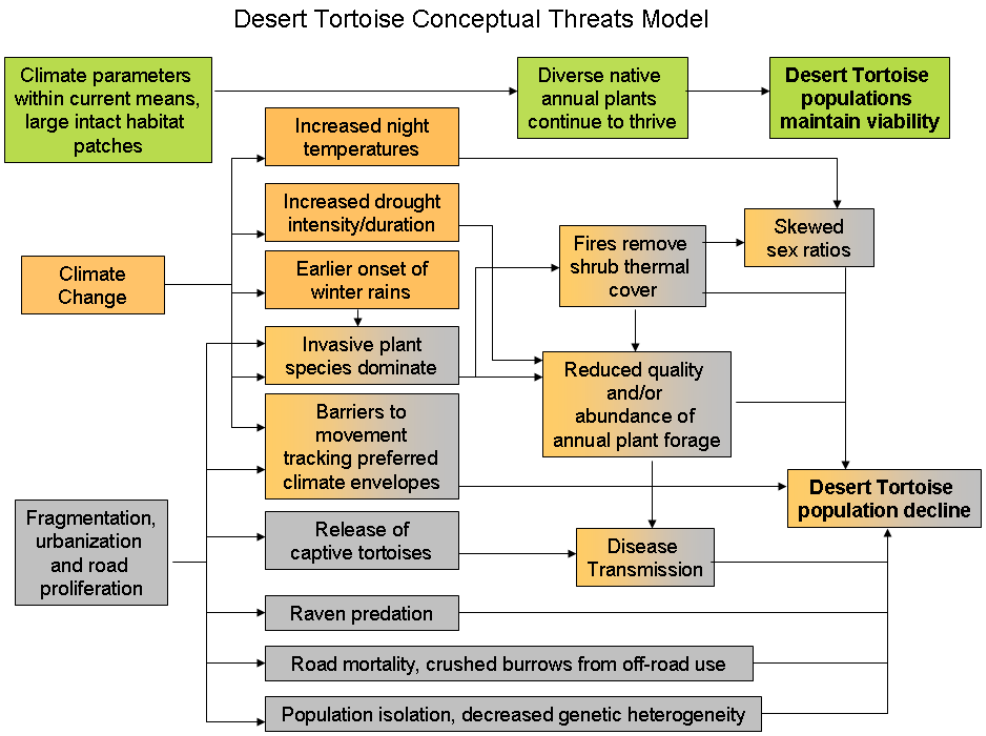

Figure 6. Desert tortoise conceptual model.

Using the Mojave fringe-toed lizard as an example of a shorter-lived species with more volatile population dynamics (Figure 7) again suggests questions about the impacts of invasive species such as Sahara mustard. Here, rather than looking at adult condition, a more straight forward approach would be to compare lizard abundances in areas with mustard and those without mustard. However to get at more proximate drivers the monitoring could also measure sand compaction and insect prey abundance with respect to the mustard as well. By measuring the mustard with respect to lizard abundance along with sand compaction and prey abundance we can evaluate whether mustard is compromising the lizards' population, and if it is, determine what pathway is driving the effect. This increases our understanding, focuses adaptive management responses, and identifies metrics for evaluating the success of mustard control measures.

Through time this hypothesis-driven process increases our understanding of how populations and communities change with respect to a range of environmental conditions. The conceptual models can be modified with new information, and ideally will evolve into quantitative, predictive models. They allow us to learn about the complex interrelationships that typify natural systems, the factors that stress natural systems, and what management tools are best used to address those stressors.

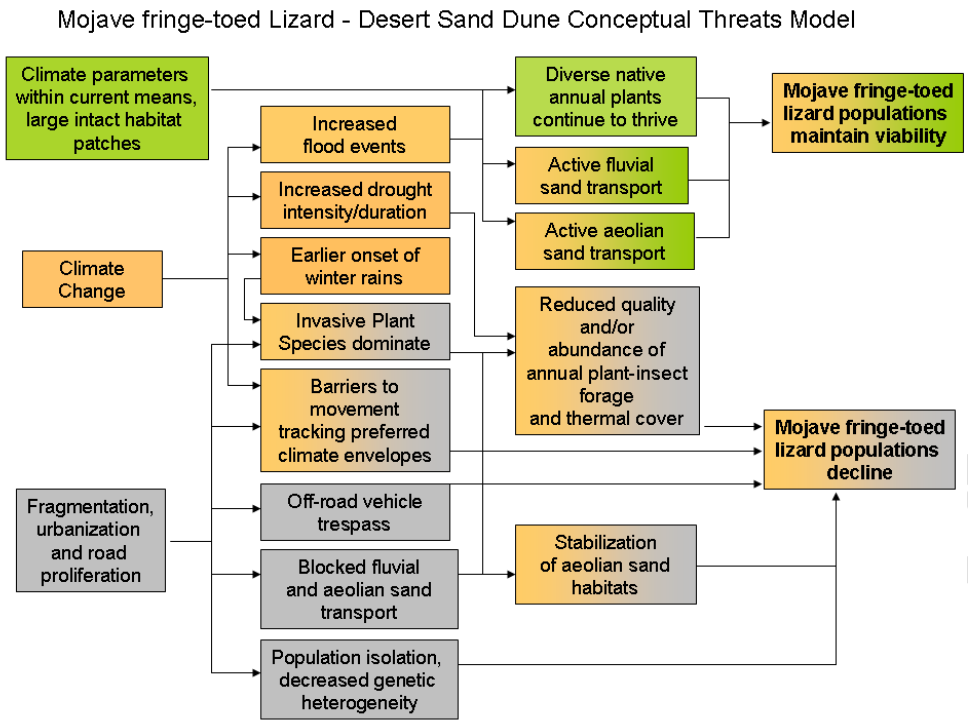

Figure 7. Mojave fringe-toed lizard conceptual model.

6.4 Monitoring Design and Research Recommendations

Renewable energy development will have impacts on species, communities, and processes that are largely unknown at this time. Mitigation for such impacts should occur via an integrated process of siting decisions, reserve establishment, and habitat management and restoration. The challenge then is to monitor both net losses and gains at various scales across the landscape. This requires systematic monitoring at impact sites, mitigation sites, and control sites (areas with no impacts or mitigation actions).

We recommend developing statistically robust monitoring designs to (1) clearly establish the effects of new developments and mitigation actions on covered species and communities, (2) better understand population distribution and dynamics of key covered or planning species, and (3) establish baseline conditions across the planning area to better understand and respond to future changes, due, for example, to climate shifts. We also endorse (4) additional research on genetic and demographic connectivity of select species' populations across the study region to better delineate important landscape connectivity areas for conservation and adaptation to climate change.

6.4.1 BACI Design for Renewable Energy Developments

Before/after - control/impact (BACI) sampling designs can be a powerful tool for understanding the impacts of anthropogenic changes on biological resources, if they are carefully designed with adequate replication and sufficient temporal sampling (Green 1979, Underwood 1994, DeLucas et al. 2005). The basic idea is to establish impact sites (e.g., areas to be developed) and control

sites (those with no development) and to sample them before the impacts occur (to establish comparable baseline conditions in the two types of sites) and after the impacts occur (for sufficient duration to observe an environmental response to the impacts). Only with this sort of design can one differentiate spatial and temporal influences to better understand potential cause-effect relationships between the development and the environmental responses. A full review of potential BACI studies and their design is beyond the scope of this report, but we recommend that the plan carefully consider the range of species, ecological conditions, and impacts that could be studied with appropriate BACI designs. *A critical issue is that access to researchers must be established in potential renewable energy development areas before, during, and after development.* DRECP should establish requirements for research and monitoring access as a condition on renewable energy permits, and should use results of BACI studies to refine siting, mitigation, and other requirements for future permits.

6.4.2 Systematic Surveys for Baseline Conditions

We recommend that a comprehensive monitoring plan be designed, at the earliest stages of plan implementation, for each covered species, community, and process of interest. Monitoring sites should be established throughout the planning area; in addition to areas with expected impacts (either positive or negative). Sites should be selected from a statistical framework (e.g., random or systematic sampling, stratified appropriately based on natural communities) at an appropriate spatial scale for the entity to be monitored. Monitoring efficiencies can be generated by co-locating sample locations for multiple species or processes of concern (Manley et al. 2004).

Results of initial monitoring should be used as "baseline" data for adaptive monitoring processes, as well as for detecting and responding to changing climatic conditions. It should be expected that design and implementation of a robust program to characterize population status, distribution, or habitat associations for some covered species will take multiple years depending on status of existing information. For instance, varying levels of precipitation altered the set of habitat variables that explained occupancy patterns of Palm Springs ground squirrel (Ball et al. 2010). Time and cost required are often cited as reasons for not establishing statistically-robust, systematic monitoring programs. However, we contend that given the presumed 30-year duration of the DRECP and our strong recommendations for an adaptive approach to conservation/mitigation/restoration, investment in a systematic, multiple-species monitoring program is a vital investment in its success.

6.4.3 Population Monitoring

Accurate estimates of covered species populations are often difficult, expensive, and unnecessary. A more reasonable approach for monitoring regional populations for most species is to use presence-absence patterns and modern site occupancy estimation measures (Scott et al. 2002, Manley et al. 2004, MacKenzie et al. 2006). These approaches are able to account for surveys where probability of detection is <1, a situation which is common for many covered species. An example of such an approach has already been implemented for the Palm Springs ground squirrel within the DRECP Planning area (Ball et al. 2010). The robustness of such approaches improves when monitoring locations are selected from a probability-based sampling method across the area of interest. Efficiencies accrue from co-locating sampling locations for multiple taxonomic groups. We recommend that such an approach be considered for monitoring

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population status of the large number of Covered Species for which detailed population information is not available.

6.4.4 Focused Research Studies and Surveys

We recommend some focused research studies and surveys for select covered species be developed to clarify how best to conserve and manage these species. Below are some examples, but others will arise during planning:

- **Mohave Ground Squirrel Surveys**. We recommend more comprehensive surveys, using appropriate systematic or random sampling designs, to better establish the distribution, abundance, and connectivity of the Mohave ground squirrel metapopulation in the western Mojave Desert. There are large gaps in existing survey efforts, and there could additional core population areas or important connectivity areas between cores than those that have been hypothesized based on existing data (Leitner 2008). Renewable energy developments should be sited so as to avoid occupied habitats or important connecting habitats, and conservation actions should strive to secure, buffer, and connect occupied and potential habitat areas.

- **Genetic and Demographic Connectivity Studies**. We endorse proposals to use population genetic data and habitat suitability modeling to provide spatially explicit inferences about important demographic connectivity areas and movement corridors. Results could be used to refine our understanding of habitat connectivity for such key species as desert tortoise and Mohave ground squirrel to inform where to focus conservation and mitigation actions to sustain or improve population connectivity to ensure species persistence in light of habitat fragmentation and climate change. However, we also endorse genetic connectivity studies across a broader range of species, including more common or unlisted species, to better understand broader, ecological implications of fragmentation and climate change on desert ecosystems.

- **Mortality monitoring**. Guidelines for producing credible mortality estimates of bats and birds at wind energy facilities in California already exist (CEC and CDFG 2007). Importantly, mortality estimates must account for biases associated with carcass removal and searcher efficiency. The existing Guidelines (CEC and CDFG 2007) should be modified for implementation at other types of renewable energy developments (e.g., solar) and associated infrastructure within the DRECP.

6.4.5 Other Environmental Monitoring

In addition to monitoring biotic conditions and processes, we recommend that at least the following physical conditions and processes should be systematically monitored using BACI designs for new developments and to establish baseline conditions and changes throughout the planning area:

- Ground water levels and impacts—e.g., to determine whether water use or hydrological effects of developments are adversely affecting water tables and dependent resources.

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- Local climate levels and impacts—e.g., to determine whether large solar arrays may affect local or regional climate conditions and hence ecological conditions.
- Erosion and deposition effects—e.g., to determine whether developments are altering soil erosion/deposition processes, eolian transport and dune maintenance processes, or levels of toxins in the atmosphere or on desert vegetation and watersheds (see Section 2.8).

6.5 Land Management Recommendations

6.5.1 Invasive Species Management

We recommend that management of exotic plants be considered as part of the energy development process and as a strategy for partly mitigating direct native habitat destruction due to energy development. It is likely that activities associated with energy development will contribute to the establishment and spread of invasive, exotic plant species. Movement of mechanized equipment can distribute seeds, construction of linear corridors (e.g., transmission lines, roads) can harbor exotics and facilitate their spread, and disturbance promotes exotic species (Lodge et al. 2006). While mitigating for direct habitat destruction by managing other lands does not fully compensate for the destroyed habitat, we suggest that managing exotics on lands adjacent to energy installations (to limit any spread of exotics due to the disturbance) and in conservation areas be considered as part of plans for partly mitigating habitat loss.

Bossard et al. (2000) summarize troublesome exotic plants of the California desert. Some species are more harmful than others. Exotic alien annuals such as Arab grass and bromes (*Schismus* sp., *Bromus rubens, B. tectorum*) now occupy over 60% of the biomass in the western, central, and southern Mojave Desert regions (Brooks and Berry 2006). The exotic annuals are highly successful, competitive, and have negative effects on native animals that rely on and prefer specific species of native food plants (e.g., desert tortoise, see Jennings 2002). Exotic annual grasses such as red brome (*Bromus rubens*) are currently of great concern to resource managers because these species are highly invasive and linked to wildfires by providing continuous fuel loads. Fires are not thought to have been prevalent historically in the Mojave Desert owing to discontinuous fuel loads, but have increased in extent in recent decades concurrently with expanding populations of exotic plants (Zouhar et al. 2008). These fires devastate native communities dominated by long-lived perennials such as blackbrush (*Coleogyne ramosissima*), which are not considered fire-adapted due to the absence of fire in the evolutionary history of the desert (Abella 2010). We suggest that an analysis of fire potential (based on fuel loads and ignition probabilities) be used as a tool for prioritizing exotic species management treatments, in conjunction with locations of sensitive species or communities with high conservation priority, and corridors where transport of exotic plants might be greatest. We recommend that equal attention be paid to high- and medium-fire potential areas. High-potential areas require treatment because of high risk; medium-potential areas can benefit from treatment to avoid becoming at risk.

Little funding for research has been dedicated to developing treatment strategies for exotic plants in southwestern hot deserts such as the Mojave. However, studies such as Allen et al. (2005) suggest that there is potential for testing different herbicides and other treatments for reducing the prevalence of red brome and other exotic plants. Key factors that should be considered in

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evaluations of herbicide and other treatment strategies include whether the herbicide acts as a pre- or post-emergent, the timing and duration required for effective treatment, and effects on the non-target native community. Additionally, consideration should be given to post-treatment management, as often establishing a competitive native vegetation type can reduce probabilities of resurgence of the exotic species. Since exotic species management strategies are not well tested in desert areas, these projects could take the form of applied projects that are conducted at an operational scale but within a planned study design that includes untreated controls. This can enable conclusions to be drawn about the effectiveness of candidate treatments and allow development of strategies that may be feasible to implement over the broad scales necessary to make a difference ecologically.

6.5.2 Restoration and Improvement of Habitat

We do not recommend considering habitat creation or ecological restoration as full mitigation for new habitat disturbances, although some habitat improvements and revegetation actions should be considered, in some cases, as partial mitigation for habitat destruction. Such actions might include revegetating disturbed areas (including by wildfires) with native plants within conservation reserves. Revegetation in arid lands is expensive and prone to failure due to unpredictable rainfall, and it is difficult to reestablish all features and processes of functional ecosystems. However, a recent review of revegetation practices in the Mojave Desert found that there are some examples of successful revegetation projects (Abella and Newton 2009).

Seeding and planting of greenhouse-grown or salvaged plants are the most common methods of revegetation. There are advantages and disadvantages to both methods; for example, larger areas can be revegetated through seeding than through planting. Associated treatments, including protecting seeds and plants from being eaten, can make the difference between successful and failed projects. Abella and Newton (2009) compiled a list of the performance of an array of native species in revegetation projects as well as the effectiveness of treatments. In addition, restoration activities such as reestablishing native riparian vegetation and hydrological patterns along springs and water courses could greatly improve habitat value and provide an adaptation strategy if the climate changes (Seavy et al. 2009). This is especially appropriate for renewable energy facilities that require significant amounts of water and may further stress groundwater supplies. Restoration efforts should not focus solely on “cosmetic” areas such as campgrounds or visitor centers, but should include meaningful areas for habitat conservation improvement purposes.

To the degree feasible, we suggest considering maintaining natural vegetation within renewable energy installations to maintain some habitat value, but carefully monitoring how this affects ecological communities and covered species. The current paradigm is to bulldoze the soil and vegetation to establish energy sites. Assessing alternative strategies that include retaining as much vegetation as possible would be a large improvement over clearing all vegetation. It is possible that that some vegetation can coexist with energy installations to provide some habitat as well as to sequester carbon. An initiative to incorporate vegetation within energy installations should include balancing any conflicts of retaining vegetation with fire hazard, maintenance and performance of the energy structures, and the ability of the vegetation to grow within the energy sites. If vegetation can co-exist within arrays, the best strategy would likely be to leave mature plants (i.e., not bulldoze them in the first place), as opposed to trying to revegetate after the fact.

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However, it is uncertain what type of native plant species are best adapted to co-exist with energy sites, so species that can thrive with shade cast by solar structures and other aspects of the sites may need to be identified and promoted. In addition, where energy installations are sited by leasing private agricultural land or private or public abandoned agricultural land, it may be possible to grow crops (or restore native desert vegetation) in concert with energy structures. Using agricultural land for energy installations has many advantages (e.g., the land is already relatively level) and is a strategy we recommend.

Monitoring should also consider whether maintaining some habitat value within renewable energy developments may do more harm than good, for example by attracting species into areas with high mortality rates. In this case, habitats within energy developments may be "sink habitats" where mortality exceeds reproduction. If this effect is strong, it has potential to reduce regional populations of covered species. Answers to such questions should be answered early if possible, by carefully designed BACI monitoring studies at developments that are permitted in the near future.

Public Draft

7 Literature Cited

Abella, S.R. 2010. Disturbance and plant succession in the Mojave and Sonoran deserts of the American Southwest. International Journal of Environmental Research and Public Health 7:1248-1284.

Abella, S.R., and A.C. Newton. 2009. A systematic review of species performance and treatment effectiveness for revegetation in the Mojave Desert, USA. Pages 45-74 *in* A. Fernandez-Bernal and M.A. De La Rosa (eds.). Arid environments and wind erosion. Nova Science Publishers, Inc., Hauppauge, NY. 394 pp.

Ackerly, D.D., S.R. Loarie, W. Cornwell, S.B. Weiss, H. Hamilton, R. Branciforte, and N.J.B. Kraft. 2010. The geography of climate change: implications for conservation biogeography. Diversity and Distributions 16:476-587.

Allen, E.B., R.D. Cox, T. Tennant, S.N. Kee, and D.H. Deutschman. 2005. Landscape restoration in southern California forblands: response of abandoned farmland to invasive annual grass control. Israel Journal of Plant Sciences 53:237-245.

American Ornithologists' Union. 1957. Check-list of North American birds, 5th ed. American Ornithologists' Union. Port City Press, Baltimore, MD.

American Ornithologists' Union. 1998. Check-list of North American birds, 7th ed. American Ornithologists' Union. Washington, D.C.

Arnett, E.B**.** (technical editor). 2005. Relationships between bats and wind turbines in Pennsylvania and West Virginia: an assessment of bat fatality search protocols, patterns of fatality, and behavioral interactions with wind turbines. A final report submitted to the Bats and Wind Energy Cooperative. Bat Conservation International, Austin, TX.

Arnett, E.B., J.P. Hayes, and M.M.P Huso. 2006. An evaluation of the use of acoustic monitoring to predict bat fatality at a proposed wind facility in south-central Pennsylvania. An annual report submitted to the Bats and Wind Energy Cooperative. Austin, TX. Bat Conservation International. 46 pp.

Arnett, E.B., M. Schirmacher, M.M.P. Huso, and J.P. Hayes. 2009. Effectiveness of changing wind turbine cut-in speed to reduce bat fatalities at wind facilities. An annual report submitted to the Bats and Wind Energy Cooperative. Bat Conservation International. Austin, TX, USA.

Arnett, E.B., W.K. Brown, W.P. Erickson, J.K. Fiedler, B.L. Hamilton, T.H. Henry, A. Jain, G.D. Johnson, J. Kerns, R.R. Koford, and others. 2008. Patterns of bat fatalities at wind energy facilities in North America. Journal of Wildlife Management 72:61-78.

Public Draft

Atkinson, A.J., P.C. Trenham, R.N. Fisher, S.A. Hathaway, B.S. Johnson, S.G. Torres, and Y.C. Moore. 2004. Designing monitoring programs in an adaptive management context for regional multiple species conservation plans. U.S. Geological Survey, Western Ecological Research Center, Sacramento, CA, in partnership with California Department of Fish and Game, Habitat Conservation Division, and U.S. Fish and Wildlife Service, Carlsbad, CA. 69 pp.

Axelrod, D.I. 1979. Age and origin of the Sonoran Desert vegetation. Occasional Papers of the California Academy of Sciences 132:1-74.

Baerwald, E. F., and R.M.R. Barclay. 2009a. Geographic variation in activity and fatality of migratory bats at wind energy facilities. Journal of Mammalogy 90:1341-1349.

Baerwald, E.F., J. Edworthy, M. Holder, and R.M.R. Barclay. 2009b. A large-scale mitigation experiment to reduce bat fatalities at wind energy facilities. Journal of Wildlife Management 73:1077-1081.

Baldwin, B.G., S. Boyd, B.J. Ertter, R.W. Patterson, T.J. Rosatti, and D.H. Wilken (eds.). 2002. The Jepson Desert Manual. University of California Press, Berkeley and Los Angeles. 624 pp.

Ball, L.C., P.F. Doherty, Jr., S.D. Ostermann-Kelm, and M.W. McDonald. 2010. Effects of rain on Palm Springs ground squirrel occupancy in the Sonoran desert. Journal of Wildlife Management 74:954-962.

Barrows, C.W. 2006. Population dynamics of a threatened dune lizard. Southwestern Naturalist 51:514-523.

Barrows, C.W., M.B. Swartz, W.L. Hodges, M.F. Allen, J.T. Rotenberry, B. Li, T.A. Scott and X. Chen. 2005. A framework for monitoring multiple species conservation plans. Journal of Wildlife Management 69:1333-1345.

Barrows, C.W., and M.F. Allen. 2007. Biological monitoring and bridging the gap between land management and science. Natural Areas Journal 27:194-197.

Beier, P., and P. Brost. 2010. Conserving the arenas not the actors: land facets as biodiversity surrogates in planning for climate change. Conservation Biology *in press.*

Beier, P, D.R. Majka, and S.L. Newell. 2009. Uncertainty analysis of least-cost modeling for designing wildlife linkages. Ecological Applications 19:2067-2077.

Beier, P., D.R. Majka, and W.D. Spencer. 2008. Forks in the road: Choices in GIS procedures for designing wildland linkages. Conservation Biology 22:836-851.

Beier, P., K. Penrod, C. Luke, W. Spencer, and C. Cabanero. 2006. South Coast Missing Linkages: restoring connectivity to wildlands in the largest metropolitan area in the

Public Draft

United States. Pages 555-586 *in*: K. Crooks and M. Sanjayan (eds.). Connectivity Conservation. Cambridge University Press.

Beissinger, S.R., J.R. Walters, D.G. Catanzaro, K.G. Smith, J.B. Dunning, Jr., S.M. Haig, B.R. Noon, and B.M. Stith. 2006. Modeling approaches in avian conservation and the role of field biologists. Ornithological Monographs No. 59. American Ornithologists' Union, Washington, D.C.

Belnap, J., R.H. Webb, M.E. Miller, D.M. Miller, L.A. DeFalco, P.A. Medica, M.L. Brooks, T.C. Esque, and D. Bedford. 2008. Monitoring ecosystem quality and function in arid settings of the Mojave Desert. U.S. Geological Survey Scientific Investigations Report 2009-5064.

Berry, K.H., E.K. Spangenberg, B.L. Homer, and E.R. Jacobson. 2002. Deaths of desert tortoises following periods of drought and research manipulation. Chelonian Conservation and Biology 4(2):436-448.

Berry, K.H., and R. Murphy (Editors). 2006. Deserts of the World. Part I: The Changing Mojave Desert. Special Issue, Journal of Arid Environments 67, Supplement.

Berry, K.H., T.Y. Bailey, and K.M. Anderson. 2006. Attributes of desert tortoise populations at the National Training Center, Central Mojave Desert, California, USA. Journal of Arid Environments 67 (Supplement):165-193.

Blair, T.C., and J.G. McPherson. 1994. Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes, and facies assemblages. Journal of Sedimentary Research 64:450-489.

Bleich, V.C. 1998. *Microtus californicus* (Peale 1848) California vole. Pages 90-92 *in* D.J. Hafner, E. Yensen, and G.L. Kirkland, (eds.). North American rodents: status survey and conservation action plan. IUCN/SSC Rodent Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. x + 171 pp.

Boarman, W.I. 1993. When a native predator becomes a pest: a case study. Pages 191-206 *in* S.K. Majumdar, E.W. Miller, D.E. Baker, E.K. Brown, J.R. Pratt, and R.F. Schmalz (eds.), Conservation and Resource Management. Pennsylvania Academy of Sciences, Easton, PA.

Boarman, W.I. 1995. Effectiveness of fences and culverts for protecting desert tortoises along California State Highway 58:1991-1994. Report to California Energy Commission. Contr. No. 700-91-005.

Boarman, W.I. 2003. Managing a subsidized predator population: reducing common raven predation on desert tortoises. Environmental Management 32:205-217.

Boarman, W.I., and K.H. Berry. 1995. Common ravens in the Southwestern United States,

Public Draft

1968-92. Pages 73-75 *in* E.L. LaRoe, G.S. Farris, and C.E. Puckett (eds.), Our Living Resources. U.S. Department of the Interior, National Biological Service, Washington, D.C.

Boarman, W.I., M. Sazaki, and W.B. Jennings. 1997. The effect of roads, barrier fences, and culverts on desert tortoise populations in California, USA. Pages 54-58 *in* van Abbema, J. (ed.), Proceedings: conservation, restoration, and management of tortoises and turtles—an international conference. New York Turtle and Tortoise Society and WCS Turtle Recovery Program.

Bossard, C.C., J.M. Randall, and M.C. Hoshovsky (eds.). 2000. Invasive plants of California's wildlands. University of California Press, Berkeley, CA, USA. 360 pp.

Breshears, D.D., J.J. Whicker, M.P. Johansen, and J.E. Pinder III. 2003. Wind and water erosion and transport in semiarid shrubland, grassland, and forest ecosystems: quantifying dominance of horizontal wind-driven transport. *Earth Surface Processes and Landforms* 28:1189-1209.

Brooks, M.L. 1995. Benefits of protective fencing to plant and rodent communities of the western Mojave Desert, California. Environmental Management 19:65-74.

Brooks, M.L. 2000. Does protection of desert tortoise habitat generate other ecological benefits in the Mojave Desert? Pages 68-73 *in* S.F. McCool, D.N. Cole, W.T. Borrie, and J. O'Laughlin (eds.). Wilderness science: in a time of change conference. Volume 3: wilderness as a place for scientific inquiry. Proceedings RMRD-P-15-VOL-3, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Brooks, M.L., and B. Lair. 2009. Ecological effects of vehicular routes in a desert ecosystem. Pages 168-195 *in* R.H. Webb, L.F. Fenstermaker, J.S. Heaton, D.L. Hughson, E.V. McDonald, D.M. Miller (eds.). The Mojave Desert: ecosystem processes and sustainability. University of Nevada Press, Reno, NV.

Brooks, M.L., and J.R. Matchett. 2003. Plant community patterns in unburned and burned blackbrush (*Coleogyne ramosissima*) shrublands in the Mojave Desert. Western North American Naturalist 63:283-298.

Brooks, M.L., and J.R. Matchett. 2006. Spatial and temporal patterns of wildfires in the Mojave Desert, 1980-2004. Journal of Arid Environments 67:148-164.

Brooks, M.L., and K.H. Berry. 2006. Dominance and environmental correlates of alien annual plants in the Mojave Desert, USA. Journal of Arid Environments 67 (Supplement):100-124.

Brooks, M.L., and T.C. Esque. 2002. Alien annual plants and wildfire in desert tortoise habitat: status, ecological effects, and management. Chelonian Conservation and Biology 4:330-

Public Draft

340.

Brown, M.B., K.H. Berry, I.M. Schumacher, K.A. Nagy, M.M. Christopher, and P.A. Klein. 1999. Seroepidemiology of upper respiratory tract disease in the desert tortoise in the western Mojave Desert of California. Journal of Wildlife Diseases 35(4):716-727.

Bunn, D., A. Mummert, M. Hoshovsky, K. Gilardi, and S. Shanks. 2007. California wildlife: conservation challenges (California's Wildlife Action Plan), 2007. 624 pp. (http://www.dfg.ca.gov/wildlife/wap/report.html)

Burnham, K.P. and D.R. Anderson. 2002. Model selection and multi-model inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, USA.

California Department of Fish and Game. 2009. List of California vegetation alliances. Biogeographic Data Branch, Vegetation Classification and Mapping Program, California Dept. of Fish and Game, Sacramento, CA. 14 pp. www.dfg.ca.gov/biogeodata/vegcamp/pdfs/Alliance List_Dec09.pdf

California Energy Commission (CEC) and California Department of Fish and Game (CDFG). 2007. California Guidelines for Reducing Impacts to Bats and Birds from Wind Energy Development. Commission final report. California Energy Commission, Renewables Committee, and Energy Facilities Siting Division, and California Department of Fish and Game, Resources Management and Policy Division. CEC-700-2007-008-CMF.

CalPIF (California Partners in Flight). 2009. Version 1.0. The desert bird conservation plan: a strategy for protecting and managing desert habitats and associated birds in California. California Partners in Flight. http://www.prbo.org/calpif/plans.html

Carroll, C., R.F. Noss, P.C. Paquet, and N.H. Schumaker. 2003. Use of population viability analysis and reserve selection algorithms in regional conservation plans. Ecological Applications 13:1773-1789.

Carroll, C. 2007. Interacting effects of climate change, landscape conversion, and harvest on carnivore populations at the range margin: marten and lynx in the Northern Appalachians. Conservation Biology 21(4):1092-1104.

Carroll, C., W. Spencer, and J.C. Lewis. In Press. Use of habitat and viability models in *Martes* conservation and restoration. In: K.B. Aubry, W.J. Zielinski, M.G. Raphael, G. Proulx, and S.W. Buskirk, eds. Biology and conservation of martens, sables, and fishers: a new synthesis.

Chaffee, M.A., and K.H. Berry. 2006. Abundance and distribution of selected elements in soils, stream sediments, and selected forage plants from desert tortoise habitats in the Mojave and Colorado deserts, USA. Journal of Arid Environments 67 (Special Supplement):35-87.

Public Draft

Chase, M.K., and G.R. Geupel. 2005. The use of avian focal species for conservation planning in California. *In* Proceedings of the Third International Partners in Flight conference, C.J. Ralph and T.D. Rich (eds.). USDA Forest Service Gen. Tech. Report PSW-GTR-191.

Chatfield, A., W. Erickson, and K. Bay. 2009. Avian and bat fatality study, Dillon Wind-Energy Facility, Riverside County, California. Western Ecosystems Technology, Inc. Cheyenne, WY, USA.

Christopher, M.M., K.H. Berry, B.T. Henen, and K.A. Nagy. 2003. Clinical disease and laboratory abnormalities in free-ranging desert tortoises (*Gopherus agassizii*) in California (1990-1995). Journal of Wildlife Diseases 39(1):35-56.

Clevenger, T., and M.P. Huijser. 2009. Handbook for design and evaluation of wildlife crossing structures in North America. Federal Highways Administration, Washington D.C.

Cole, K.C., K. Ironside, J. Eischeid, G. Garfin, P. Duffy, and C. Toney. *In Press*. Past and ongoing shifts in Joshua tree support future modeled range contraction. Ecological Applications.

Comstock, J.P., and J.R. Ehleringer. 1992. Plant adaptation in the Great Basin and Colorado Plateau. Great Basin Naturalist 52:195-215.

Croker, R.A. 1991. Pioneer ecologist: the life and work of Victor Ernest Shelford. Smithsonian Institution Press, Washington, D.C.

Crooks, K. R. 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. Conservation Biology 16:488-502.

Dahm, C., T. Dunne, W. Kimmerer, D. Reed, E. Soderstrom, W. Spencer, S. Ustin, J. Wiens, and I. Werner. 2009. Bay Delta Conservation Plan Independent Science Advisors' Report on Adaptive Management. Prepared for BDCP Steering Committee. February 2009. DRECP ISA Report Draft 6 25 10.doc

DeFalco, L.A., T.C. Esque, J.M. Kane, M.B. Nicklas. 2009. Seed banks in a degraded desert shrubland: influence of soil surface condition and harvester ant activity on seed abundance. Journal of Arid Environments 73:885-893.

DeFalco, L.A., T.C. Esque, S.J. Scoles, and J. Rodgers. 2010. Desert wildfire and severe drought diminish survivorship of the long-lived Joshua tree (*Yucca brevifolia*; Agavaceae). American Journal of Botany 97:243-250.

DeLucas, M., G.F.E. Janss, and M. Ferrer. 2005. A bird and small mammal BACI and IG design studies in a wind farm in Malpica (Spain). Biodiversity and Conservation 14(13):3298-3303. DOI 10.1007/s10531-004-0447-z.

Public Draft

Early, R., B. Anderson, and C.D. Thomas. 2008. Using habitat distribution models to evaluate large-scale landscape priorities for spatially dynamic species. J. Applied Ecology 45:228-238.

Edwards T, C.R. Schwalbe, D.E. Swann, and C.S. Goldberg. 2004. Implications of anthropogenic landscape change on inter-population movements of the desert tortoise (*Gopherus agassizii*). Conservation Genetics 5:485–499.

Elith, J., C.H. Graham, and NCEAS Species Distribution Modelling Group. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29:129-151.

Elith, J., and J. Leathwick. 2009. Species distribution models: ecological explanation and prediction across space and time. Annual Review of Ecology, Evolution and Systematics 40:677-697.

Epps, C.W., J.D. Wehausen, V.C. Bleich, S.G. Torres, and J.S. Brashares. 2007. Optimizing dispersal and corridor models using landscape genetics. Journal of Applied Ecology 44:714-724.

Esque, T.C., K.E. Nussear, K.K. Drake, A.D. Walde, K.H. Berry, R.C. Averill-Murray, A.P. Woodman, W.I. Boarman, P.A. Medica, J. Mack J.S. Heaton. In Press. Effects of human population density, resource variability, and subsidized predators on desert tortoise populations in the Mojave Desert. Endangered Species Research.

FGDC (Federal Geographic Data Committee). 2008. National vegetation classification standard, version 2. FGDC-STD-005-2008. Federal Geographic Data Committee, FGDC Secretariat, U.S. Geological Survey, Reston, VA. Pages 18-21 *in* J.O. Sawyer, T. Keeler-Wolf, and J.M. Evens. 2008. A manual of California vegetation, second edition. California Native Plant Society, Sacramento, CA.

Fitzpatrick, J.W. 2010. Subspecies are for convenience. Ornithological Monographs 67:54-61.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. Wiley, NY.

Griffiths, P.G., R.H. Webb, N. Lancaster, C.A. Kaehler, and S.C. Lundstrom. 2002. Long-term sand supply to Coachella Valley fringe-toed lizard (*Uma inornata*) habitat in the northern Coachella Valley, California. U.S. Geological Survey Water-Resources Investigations Report 02-4013.

Grossman, D.H., K. Goodin, M. Anderson, P. Bourgeron, M.T. Bryer, R. Crawford, L. Engelking, D. Faber-Langendoen, M. Gallyoun, S. Landaal, K. Metzler, K.D. Patterson, M. Pyne, M. Reid, L. Sneddon, and A.S. Weakley. 1998. International classification of ecological communities: terrestrial vegetation of the United States. The Nature Conservancy. Arlington, VA.

Public Draft

Grove, R.H. 1992. Origins of western environmentalism. Scientific American, July 42-47.

Guisan, A., C.H. Graham, J. Elith, F. Huettmann, and NCEAS Species Distribution Modelling Group. 2007. Sensitivity of predictive species distribution models to change in grain size: insights from a multi-models experiment across five continents. *Diversity and Distributions* 13:332-340.

Guisan, A., and W.T. Thuiller. 2005. Predicting species distribution: offering more than simple habitat models. Ecology Letters 8:993-1009.

Hafner, M.S. 1977. Density and diversity in the Mojave Desert rodent and shrub communities. Journal of Animal Ecology 46:925-938.

Haig, S.M., and J.D'Elia. 2010. Avian subspecies and the U. S. Endangered Species Act. Ornithological Monographs 67:24-34.

Hagerty, B.E., K.E. Nussear, T.C. Esque, and C.R. Tracy. *In Review*. More than isolation by distance: a landscape genetic approach to identifying the population structure of the Mojave desert tortoise.

Hagerty B.E., and C.R. Tracy. 2010. Defining population boundaries for the Mojave desert tortoise. Conservation Genetics DOI 10.1007/s10592-010-0073-0.

Hamerlynck, E.P., J.R. McAuliffe, E.V. McDonald, and S.D. Smith. 2002. Ecological responses of two Mojave Desert shrubs to soil horizon development and soil water dynamics. Ecology 83:768-779.

Harris, L.D. 1984. The fragmented forest: island biogeography theory and the preservation of biotic diversity. University of Chicago Press, Chicago, IL.

Hayhoe, K., and 18 others. 2004. Emissions pathways, climate change, and impacts on California. Proc. Nat. Acad. Sci. 101:12422-12427.

Heaton, J.S., K.E. Nussear, T.C. Esque, R. Inman, F.M. Davenport, T.E. Leuteritz, P.A. Medica, N.W. Strout, P.A. Burgess, and L. Benvenuti. 2008. Spatially explicit decision support for selecting translocation areas for desert tortoises. Biological Conservation DOI 10.1007/s10531-007-9282-3.

Helgen, K.M.; F.R. Cole, L.E. Helgen, and D.E. Wilson. 2009. Generic revision in the holarctic ground squirrel genus *Spermophilus*. Journal of Mammalogy 90:270–305. doi:10.1644/07-MAMM-A-309.1

Hereford, R., R.H. Webb, and C. Longpré. 2006. Precipitation history and ecosystem response to multidecadal precipitation variability in the Mojave Desert and vicinity, 1893-2001. Journal of Arid Environments (Supplement) 67:13-34.

Public Draft

Holland, R.F. 1986. Preliminary descriptions of terrestrial natural vegetation of California. California Department of Fish and Game. Sacramento, CA.

Holling, C.S. 1978. Adaptive experimental assessment and management. John Wiley & Sons, New York, NY, USA.

Homer, B.L., K.H. Berry, M.B. Brown, G. Ellis, and E.R. Jacobson. 1998. Pathology of diseases in desert tortoises from California. Journal of Wildlife Diseases 34(3):508-523.

Hooper, S., K. Hunting, and M. Parisi. 2009. Range map review and revision project: instructions for revising mammal range maps. Unpublished draft prepared by the California Wildlife Habitat Relationships Program. California Department of Fish and Game, Sacramento, CA.

Horvath, G., M. Blaho, A. Egri, G. Kriska, I. Seres, and B. Robertson. 2010. Reducing the maladaptive attractiveness of solar panels to polarotactic insects. Conservation Biology. DOI 10.1111/j.1523-1739.2010.01518.x.

Jacobson, E.R., T.J. Wronski, J. Schumacher, C. Reggiardo, and K.H. Berry. 1994. Cutaneous dyskeratosis in free-ranging desert tortoises, *Gopherus agassizii*, in the Colorado Desert of Southern California. J. Zoo and Wildlife Medicine 25(1):68-81.

Jennings, W.B. 2002. Diet selection by the desert tortoise in relation to the flowering phenology of ephemeral plants. Chelonian Conservation and Biology 4(2):353-358.

Jenny, H. 1941. Factors of soil formation: a system of quantitative pedology. McGraw-Hill Book Company, Inc., New York.

Johnson, A.J., D.J. Morafka, and E.R. Jacobson. 2006. Seroprevalence of *Mycoplasma agassizii* and tortoise herpesvirus in captive desert tortoises (*Gopherus agassizii*) from the Greater Barstow Area, Mojave Desert, California. Journal of Arid Environments 67 (Supplement):165-191.

Kerr, R.A. 2008. Climate change hot spots mapped across the United States. Science 321:909.

Knight, R.L., H.A.L. Knight, and R.J. Camp. 1993. Raven populations and land-use patterns in the Mojave Desert, California. Wildlife Society Bulletin 21:469-471.

Kochert, M.N., K. Steenhof, C.L. McIntyre, and E.H. Craig. 2002. Golden eagle (*Aquila chrysaetos*) *in* A. Poole and F. Gill (eds.), The Birds of North America, No. 684. The Birds of North America, Inc., Philadelphia, PA.

Kristan, W.B, III, and W.I. Boarman. 2003. Spatial pattern of risk of common raven predation on desert tortoises. Ecology 84:2432-2443.

Public Draft

Lambeck, R.J. 1997. Focal species: a multi-species umbrella for nature conservation. Conservation Biology 11:849-865.

Landres, P.B., P. Morgan, and F.J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9:1179-1188.

Leitner, P. 2008. Current status of the Mohave ground squirrel. Transactions of the Western Section of The Wildlife Society 44:11-29.

Leung, Y. 1997. Intelligent spatial decision support systems. Springer-Verlag, Berlin.

Llewellyn, D.W., G.P. ShaVer, N.J. Craig, L. Creasman, D. Pashley, M. Swan, and C. Brown. 1996. A decision-support system for prioritizing restoration sites on the Mississippi River alluvial plain. Conservation Biology 10:1446–1455.

Loarie, S.R., P.B. Duffy, H. Hamilton, G.P. Asner, C.B. Field, and D.D. Ackerly. 2009. The velocity of climate change. Nature 462:1052-1055.

Lodge, D.M., S. Williams, H.J. MacIsaac, K.R. Hayes, B. Leung, S. Reichard, R.N. Mack, P.B. Moyle, M. Smith, D.A. Andow, J.T. Carlton, and A. McMichael. 2006. Biological invasions: recommendations for U.S. policy and management. Ecological Applications 16:2035-2054.

Longshore, K.M., J.R. Jaeger, and J.M. Sappington. 2003. Desert tortoise (*Gopherus agassizii*) survival at two eastern Mojave Desert sites: death by short-term drought? Journal of Herpetology 37:169–177.

Lovich, J.E., and D. Bainbridge. 1999. Anthropogenic degradation of the southern California desert ecosystem and prospects for natural recovery and restoration. Environmental Management 24:309-326.

MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, LL. Bailey, and J.E. Hines. 2006. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. London, U.K.: Elsevier Academic Press. 324 pp.

Marticorena B., G. Bergametti, B. Aumont, Y. Callot, C.N. 'Doumé, and M. Legrand. 1997. Modeling the atmospheric dust cycle: 2-Simulations of Saharan dust sources. J. Geophys. Res. 102:4387-4404.

McRae, B.H., B.G. Dickson, T.H. Keitt, and V.B. Shah. 2008. Using circuit theory to model connectivity in ecology, evolution, and conservation. Ecology 89:2712-2724.

McRae, B.H., and P. Beier. 2007. Circuit theory predicts gene flow in plant and animal populations. Proceedings of the National Academy of Sciences of the United States of America 104:19885–19890.

Public Draft

Manley, P.N., W.J. Zielinski, M.D. Schlesinger, and S.R. Mori. 2004. Evaluation of a multiple-species approach to monitoring species at the ecoregional scale. Ecological Applications 14:296-310.

Margules, C.R., and R.L. Pressey. 2000. Systematic conservation planning. Nature 405:243-253.

McAuliffe, J.R. 1994. Landscape evolution, soil formation, and ecological patterns and processes in Sonoran desert bajadas. Ecological Monographs 64:111-148.

McAuliffe, J.R. 2003. The interface between precipitation and vegetation: the importance of soils in arid and semi-arid environments. Pages 9-27 *in* J.F. Weltzin and G.R. McPherson (eds.). Changing precipitation regimes and terrestrial ecosystems: a North American perspective. University of Arizona Press.

McFadden, L.D., and P.L.K. Knuepfer. 1990. Soil geomorphology: the linkage of pedology and surficial processes. Geomorphology 3:197-205.

Meese, R.J., F.M. Shilling, and J. Quinn. 2009. Wildlife crossings guidance manual. California Department of Transportation, Sacramento. http://www.dot.ca.gov/hq/env/bio/wildlife_crossings/

Miles, S.R., C.B. Goudey, E.B. Alexander, and J.O. Sawyer. 1998. Ecological subregions of California. Section and subsection descriptions. USDA, Forest Service, Pacific Southwest Region, San Francisco, CA. Internet number R5-EM-TP-005-NET. http://www.fs.fed.us/r5/projects/ecoregions/

Miller, D.M., D.R. Bedford, D.L. Hughson, E.V. McDonald, S.E. Robinson, and K.M. Schmidt. 2009. Mapping Mojave Desert ecosystem properties with surficial geology. Pages 252-277 *in* R.H. Webb, L.F. Fenstermaker, J.S. Heaton, D.L. Hughson, E.V. McDonald, D.M. Miller (eds.). The Mojave Desert: ecosystem processes and sustainability. University of Nevada Press, Reno, NV.

Miller, M.E, J. Belnap, S.W. Beatty, and R.L. Reynolds. 2006. Performance of *Bromus tectorum* L. in relation to soil properties, water additions, and chemical amendments in calcareous soil of southeastern Utah, USA. Plant Soil 288: 1-18.

Moilanen, A., A.M.A. Franco, R. Early, R. Fox, B. Wintle, and C.D. Thomas. 2005. Prioritizing multiple use landscapes for conservation: methods for large multi species planning problems. Proc. R. Soc. Lond. B Biol. Sci. 272:1885-1891.

Moilanen, A., K. Wilson, and H. Possingham (eds.). 2009. Spatial conservation prioritization: quantitative methods and computational tools. New York: Oxford University Press. 320 pp.

Public Draft

Morrison, M.L., W.M. Block, M.D. Strickland, and W.L. Kendall. 2001. Wildlife study design. Springer-Verlag, New York, NY, USA.

Murphy, M.T. 2002. Source-sink dynamics of a declining eastern kingbird population and the value of sink habitats. Conservation Biology 15:737-748.

Murphy, R, K.H. Berry, T. Edwards, and A. McLuckie. 2007. A genetic assessment of the recovery units for the Mojave population of desert tortoises, *Gopherus agassizii*. Chelonian Conservation and Biology 6(2):229-251.

Nabhan, G.P., and J.L. Carr. 1994. Ironwood: an ecological and cultural keystone of the Sonoran Desert. Conservation International, Washington, D.C. 94 pp.

New, T.R. 1993. Angels on a pin: dimensions of the crisis in invertebrate conservation. Amer. Zool. 33:623-630.

New, T.R. 1999. Limits to species focusing in insect conservation. Ann. Entomol. Soc. Am. 92:853-860.

Norris, R.M., and K.S. Norris. 1961. Algodones Dunes of southeastern California. Geological Society of America Bulletin 72, 605-620.

Noss, R.F. 1987. From plant communities to landscapes in conservation inventories: a look at The Nature Conservancy (USA). Biological Conservation 41:11-37.

Noss, R.F., and A. Cooperrider. 1994. Saving nature's legacy: protecting and restoring biodiversity. Island Press, Washington, D.C. 416 pp.

Noss, R.F., C. Carroll, K. Vance-Borland, and G. Wuerthner. 2002. A multicriteria assessment of the irreplaceability and vulnerability of sites in the Greater Yellowstone Ecosystem. Conservation Biology 16:895-908.

Noss, R.F., J.R. Strittholt, K. Vance-Borland, C. Carroll, and P. Frost. 1999. A conservation plan for the Klamath-Siskiyou ecoregion. Natural Areas Journal 19(4): 392-410.

Noss, R.F., M.A. O'Connell, and D.D. Murphy. 1997. The science of conservation planning: habitat conservation under the endangered species Acto. Island Press: Washington D.C., Covelo, CA. 246 pp.

Nussear, K.E., T.C. Esque, R.D. Inman, K.A. Thomas, L. Gass, C.S.A. Wallace, J.B. Blainey, D.M. Miller, and R.H. Webb. 2009. Modeling habitat of desert tortoise (*Gopherus agassizii*) in the Mojave and parts of the Sonoran Deserts, California, Nevada, Utah, and Arizona: U.S. Geological Survey open-file report 2009-1102. 18 pp. http://pubs.usgs.gov/of/2009/1102/

Public Draft

O'Conner, R.J. 2002. The conceptual basis of species distribution modeling: time for a paradigm shift? Pages 25-33 *in* J.M. Scott, P.J. Heglund, and M.L. Morrison, et al. (eds.). Predicting species occurrences: issues of accuracy and scale. Island Press, Washington, D.C. 868 pp.

Oreskes, N. 2004. The scientific consensus on climate change. Science 306:1686-1689.

Patton, J.L., D.G. Huckaby, and S.T. Alvarez Casteneda. 2007. The evolutionary history and a systematic revision of woodrats of the Neotoma lepida group. University of California Press, Berkeley, CA. 472pp.

Pavich, M.J., and O.A. Chadwick. 2003. Soils and the Quaternary climate system. Pages 311-330 *in* Gillespie, A.R., S.C. Porter, and B.F. Atwater (eds.). The Quaternary period in the United States. Amsterdam, Elsevier.

Pavlik, B.M. 2008. The California deserts: an ecological rediscovery. University of California Press.

Penrod, K., P. Beier, P. Huber, and E. Garding. In prep. A strategy for maintaining and restoring connectivity to the California deserts. SC Wildlands, Fair Oaks, CA. www.scwildlands.org.

Possingham, H.P., I.R. Ball, S. Andelman. 2000. Mathematical methods for identifying representative reserve networks. Pages 291–305 *in* S. Ferson and M. Burgman (eds.). Quantitative methods for conservation biology. Springer-Verlag, NY.

Quinn, J.H. 2008. The ecology of the American badger Taxidea taxus in California: assessing conservation status on multiple scales. Ph.D. Dissertation, University of California, Davis.

Rahn, M.E., H. Doremus, and J. Diffendorfer. 2006. Species coverage in multispecies habitat conservation plans: where's the science? BioScience 56(7):613-619.

Redak, R.A. 2000. Arthropods and multispecies habitat conservation plans: are we missing something? Environmental Management 26S:97-107.

Remsen, J.V., Jr. 2010. Subspecies as a meaningful taxonomic rank in avian classification. Ornithological Monographs 67: 62-78.

Reynolds, R.L., J. Belnap, M. Reheis, P. Lamothe, and F. Luiszer. 2001. Eolian dust in Colorado Plateau soils: nutrient inputs and recent change in source. Proceedings of the National Academy of Sciences, vol. 98:7123-7127.

Rowlands, P.G. 1995. Regional bioclimatology of the California Desert. Pages 95-134 *in* J. Latting, and P.G. Rowlands (eds.). The California Desert: an introduction to natural

Public Draft

resources and man's impact, volume 1. University of California Riverside Press, Riverside, CA.

Rowlands, P.G., H. Johnson, E. Ritter, and A. Endo. 1982. The Mojave Desert. Pages 1-3-162 *in* Bender, G.L. (ed.) Reference handbook on the deserts of North America. Greenwood Press, Westport, CT.

Sawyer, J.O., T. Keeler-Wolf, and J.M. Evens. 2009. A manual of California vegetation, 2nd edition. California Native Plant Society, Sacramento, CA.

Schumaker, N.H. 1998. A user's guide to the PATCH model. EPA/600/R-98/135. U.S. Environmental Protection Agency. Environmental Research Laboratory, Corvallis, Oregon, USA.

Scott, J.M., P.J. Heglund, M.L. Morrison, et al. 2002. Predicting species occurrences: issues of accuracy and scale. Island Press, Washington, D.C. 868 pp.

Seavy, N.E. and C.A. Howell. 2010. How can we improve delivery of decision support tools for conservation and restoration? Biodiversity and Conservation 19:1261–1267.

Seavy, N.E., T. Gardali, G.H. Golet, F.T. Griggs, C.A. Howell, T.R. Kelsey, S. Small, J.H. Viers, and J.F. Weigand. 2009. Why climate change makes riparian restoration more important than ever. Ecological Restoration 27:330-338.

Sharifi, M.R., A.C. Gibson, and P.W. Rundel. 1997. Surface dust impacts on gas exchange in Mojave desert shrubs. The Journal of Applied Ecology 34:837-846.

Sharifi, M.R., A.C. Gibson, and P.W. Rundel. 1999. Phenological and physiological responses of heavily dusted creosote bush (*Larrea tridentata*) to summer irrigation in the Mojave Desert. Flora 194: 369-378.

Shuford, W.D., and T. Gardali (eds.). 2008. California bird species of special concern: a ranked assessment of species, subspecies, and distinct populations of birds of immediate conservation concern in California. Studies of western birds, no. 1. Western Field Ornithologists, Camarillo, CA. and California Department of Fish and Game, Sacramento, CA.

Slater, S.J. and J.P. Smith. 2010. Effectiveness of raptor perch deterrents on an electrical transmission line in southwestern Wyoming. Journal of Wildlife Management 74:1080-1088.

Smallwood, K.S., and B. Karas. 2009. Avian and bat fatality rates at old-generation and repowered wind turbines in California. Journal of Wildlife Management 73:1062-1071.

Smallwood, K.S., L. Neher, D. Bell, J. DiDonato, B. Karas, S. Snyder, and S. Lopez. 2009. Range management practices to reduce wind turbine impacts on burrowing owls and

Public Draft

other raptors in the Altamont Pass Wind Resource Area, California. Report no. CEC-500-2008-080 to the California Energy Commission, Public Interest Energy Research - Environmental Area, Sacramento, USA.

Smith, S.D., C.A. Herr, K.L. Leary, and J.M. Piorkowski. 1995. Soil-plant water relations in a Mojave Desert mixed shrub community: a comparison of three geomorphic surfaces. Journal of Arid Environments 29(3):339-351.

Soulé, M.E., and D. Simberloff. 1986. What do genetics and ecology tell us about the design of nature reserves? Biological Conservation 35:19-40.

Soulé, M.E., and J. Terborgh (eds.). 1999. Continental conservation: scientific foundations of regional reserve networks. Island Press.

Soulé, M.E., J.A. Estes, J. Berger, and C.M. Del Rio. 2003. Ecological effectiveness: conservation goals for interactive species. Conservation Biology 17:1238–1250.

South Coast Wildlands. 2008. South Coast Missing Linkages: a wildland network for the South Coast Ecoregion. http://www.scwildlands.org.

Spencer, W.D., H. Rustigian, R.M. Scheller, J.R. Strittholt, W.J. Zielinski, and R. Truex. In Press. Using occupancy and population models to assess habitat conservation opportunities for an isolated carnivore population. Biological Conservation.

Spencer, W.D., P. Beier, K. Penrod, K. Winters, C. Paulman, H. Rustigian-Romsos, J. Strittholt, M. Parisi, and A. Pettler. 2010. California Essential Habitat Connectivity Project: A strategy for conserving a connected California. Prepared for California Department of Transportation, California Department of Fish and Game, and Federal Highways Administration. February.

Spencer, W.D., H.L. Rustigian, R.M. Scheller, A. Syphard, J. Strittholt, and B. Ward. 2008. Baseline evaluation of fisher habitat and population status, and effects of fires and fuels management on fishers in the southern Sierra Nevada. Unpublished report prepared for USDA Forest Service, Pacific Southwest Region. June 2008. 133 pp + appendices.

Spencer W.D., S. Osborne, et al. *In prep*. California mammal species of special concern. Prepared for California Department of Fish and Game.

Stevenson, B.A., E.V. McDonald, and T.G. Caldwell. 2009. Root patterns of *Larrea tridentata* in relation to soil morphology in Mojave Desert soils of different ages. Pages 312-338 *in* R.H. Webb, L.F. Fenstermaker, J.S. Heaton, D.L. Hughson, E.V. McDonald, and D.M. Miller (eds.). The Mojave Desert: ecosystem processes and sustainability. University of Nevada Press, Reno, NV.

Public Draft

Stralberg, D., D. Jongsomjit, C.A. Howell, M.A. Snyder, J.D. Alexander, J.A. Wiens, and T.L. Root. 2009. Re-shuffling of species with climate disruption: a no-analog future for California birds? PLoS ONE 4:1-8.

Thomas, K., T. Keeler-Wolf, J. Franklin, and P. Stine. 2004. Mojave Desert Ecosystem Program: Central Mojave vegetation database. U.S Geological Survey, Sacramento, CA.

Tingley, M.W., W.B. Monahan, S.R. Beissinger, and C. Moritz. 2009. Birds track their Grinnellian niche through a century of climate change. Proceedings of the National Academy of Science 106(suppl. 2):19637-19643.

Titus, J.H., R.S. Nowak, and S.D. Smith. 2002. Soil resource heterogeneity in the Mojave Desert. Journal of Arid Environments 52:269-292.

Tracy C.R., R.C. Averill-Murray, W.I. Boarman, D.J. Delehanty, J.S. Heaton, E.D. McCoy, D.J. Morafka, K.E. Nussear, B.E. Hagerty, and P.A. Medica. 2004. Desert tortoise recovery plan assessment. Technical report to U.S. Fish and Wildlife Service, Reno, NV. 254 pp.

Underwood, A.J. 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. Ecological Applications, 4(1):3-15. DOI: 10.2307/1942110.

UNESCO. 1974. Task force on criteria and guidelines for the choice and establishment of biosphere reserves. Man and the Biosphere report, no. 22. Paris, France.

U.S. Department of the Interior, Bureau of Land Management. 1980, as amended. The California Desert Conservation Area Plan 1980. Bureau of Land Management, Riverside, CA. (*note: this particular reference could be updated and potentially the regional plans could be cited*).

U.S. Fish and Wildlife Service (USFWS). 1994. Desert tortoise (Mojave population) recovery plan. U.S. Fish and Wildlife Service, Portland, OR. 73 pp (plus appendices).

Vander Wall, S.B., T. Esque, D. Haines, and M. Garnett, and B.A. Waitman. 2006. Joshua tree (*Yucca brevifolia*) seeds are dispersed by seed-caching rodents. Ecoscience 13(4):539-543.

van Donk, S.J., X.W. Huang, E.L. Skidmore, A.B. Anderson, D.L Gebhart, V.E. Prehoda, and E.M. Kellogg. 2003. Wind erosion from military training lands in the Mojave Desert, California, USA. Journal of Arid Environments 54:687–703.

Waitman, B.A. 2009. Rodent mediated seed dispersal of Joshua tree (*Yucca brevifolia*). Thesis. University of Nevada, Reno. 51 pp.

Walters, C.J. 1986. Adaptive management of renewable resources. MacMillan, New York, USA.

Public Draft

Webb, R.H., J.S. Heaton, M.L. Brooks, and D.M. Miller. 2009a. Introduction. Pages 1-6 *in* R.H. Webb, L.F. Fenstermaker, J.S. Heaton, D.L. Hughson, E.V. McDonald, and D.M. Miller (eds.). The Mojave Desert: ecosystem processes and sustainability. University of Nevada Press, Reno, NV.

Webb, R.H., J. Belnap, and K.A. Thomas. 2009b. Natural recovery from severe disturbance in the Mojave Desert. Pages 343-377 *in* R.H. Webb, L.F. Fenstermaker, J.S. Heaton, D.L. Hughson, E.V. McDonald, D.M. Miller (eds.). The Mojave Desert: ecosystem processes and sustainability. University of Nevada Press, Reno, NV.

Webb, R.H., L.F. Fenstermaker, J.S. Heaton, D.L. Hughson, E.V. McDonald, D.M. Miller (eds.). 2009c. The Mojave Desert: ecosystem processes and sustainability. University of Nevada Press, Reno, NV.

Weller, T.J. 2008. Evaluating pre-construction sampling regimes for assessing patterns of bat activity at a wind energy development in southern California. PIER Energy-Related Environmental Research Program. Report no. CEC-500-01-032. 24 pp.

Whitford, W.G. 2002. Ecology of desert systems. Academic Press.

Wiens, J.A., Stralberg, D., D. Jongsomjit, C.A. Howell, M.A. Snyder. 2009. Niches, models, and climate change: assessing the assumptions and uncertainties. Proceedings of the National Academy of Sciences, vol. 106(Supplement 2):19729-19736.

Wilcove, D.S., and D.D. Murphy. 1991. The spotted owl controversy and conservation biology. Conservation Biology 5:261-262.

Williams, D.F. 1986. Mammalian species of special concern in California. Wildlife Management Division Administrative Report 86-l. CDFG. 112 pp.

Wilson, E.O. 1988. The current state of biological diversity. *In* E. O. Wilson (ed.). Biodiversity. National Academy Press. Washington, D.C.

Wintle, A.G., N. Lancaster, and S.R. Edwards. 1994. Infrared stimulated luminescence (IRSL) dating of late-Holocene aeolian sands in the Mojave Desert, California, USA. The Holocene 4:74-78.

Woodroffe, R. and J.R. Ginsberg. 1998. Edge effects and the extinction of populations inside protected areas. Science 280(5372):2126-2128.

Zouhar, K., J.K. Smith, S. Sutherland, and M.L. Brooks (eds.). 2008. Wildland fire in ecosystems: fire and nonnative invasive plants. General technical report RMRS-GTR-42-vol. 6. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT. 355 pp.

Public Draft

Appendix A

Biographies of Advisors

Dr. Scott R. Abella, Assistant Research Professor, School of Environmental and Public Affairs, University of Nevada Las Vegas. Dr. Abella's research focus is applied ecology for supporting land management and conservation, in the areas of plant ecology, restoration ecology, fire ecology, and scientific literature synthesis. He regularly works directly with resource managers on projects, enabling mutually beneficial science-management partnerships and clear paths for scientific information transfer. Dr. Abella has published over 50 scientific papers and has nine years of applied research experience in the Southwest. His work is regularly sought by media outlets such as the Las Vegas Sun, and he is invited to 4-6 conferences annually as a featured speaker on topics such as ecological restoration, fire management, and exotic species in southwestern deserts. He teaches UNLV courses in restoration ecology, undergraduate and graduate research, ecology, and environmental science.

Dr. Cameron Barrows, Assistant Research Ecologist, University of California, Riverside's Center for Conservation Biology. Dr. Barrows' research addresses many aspects of Conservation Biology and includes 1) Community ecology of arid environments, 2) Climate change sensitivity of desert flora and fauna, 3) The development of ecological criteria for evaluating multiple species conservation efforts, and 4) the impacts of invasive species on the biodiversity of Southwestern landscapes. He served on the Scientific Advisory Committee for Biological Monitoring component of that plan. Recent publications include: Persistence and local extinctions of an endangered lizard on isolated habitat patches, (Barrows, C. W. and M. F. Allen. Endangered Species Research 3:61-68), Using occurrence records to model historic distributions and estimate habitat losses for two psammophilic lizards, (Barrows C. W., K. L. Preston, J. T. Rotenberry, M. F. Allen. Biological Conservation 141:1885-1893), Effects of an invasive plant on a desert sand dune landscape (Barrows, C. W., E. B. Allen, M. L. Brooks, and M. F. Allen. Biological Invasions 11:673-686), Conserving Species in Fragmented Habitats: Population Dynamics of the Flat-tailed Horned Lizard, *Phrynosoma mcallii* (Barrows, C. W. and M. F. Allen. Southwestern Naturalist 54: 307-316, Patterns of occurrence of reptiles across a sand dune landscape (Barrows, C. W. and M. F. Allen. Journal of Arid Environments 74:186-192), and Assessing sensitivity to climate change and drought variability of a sand dune endemic lizard (Barrows, C. W., J. T. Rotenberry, and M. F. Allen. Biological Conservation 143:731-743).

Dr. Kristin H. Berry, Research Wildlife Biologist, U.S. Geological Survey, Riverside, California. Dr. Berry is a wildlife biologist and arid lands ecologist with expertise in plant and animal communities in the Mojave and western Sonoran deserts, the desert tortoise and other vertebrates. She has degrees from Stanford University (B.A., 1964), University of California at Los Angeles (M.A., 1968), and University of California, Berkeley (Ph.D., 1972), and has been an employee of the Department of the Interior since 1974. Dr. Berry has published over 50 scientific papers on desert topics and edited a volume of scientific papers on the Mojave Desert,

which was published in 2006. Her field research covers a wide variety of topics, including ecology, behavior, and impacts of translocation on tortoises; health and diseases of desert tortoises; recovery of annual and perennial vegetation after disturbance; anthropogenic impacts in the desert and the relationship to population declines of the tortoise; and invasive annual plants. Berry conducts interdisciplinary research with research veterinary pathologists and microbiologists, geneticists, botanists, and geologists. She provides data and recommendations to wildlife biologists and managers in federal and state agencies and contributes to land-use plans.

Dr. Todd C. Esque, Research Ecologist, Western Ecological Research Center, US Geological Survey, Henderson Nevada. Dr. Esque's research focuses on disturbance ecology in arid systems. His academic training was at Prescott College Arizona (B.A), Colorado State University (M. Sc. – Biology), and University of Nevada, Reno (Ecology, Evolution and Conservation Biology). Active research includes fire ecology, community and landscape ecology, herpetology and conservation biology. Dr. Esque serves on academic committees at universities and participates in science advisory committees for a variety of applied research initiatives. Recent publications include: (1) Esque, T.C., J.A. Young, and C.R. Tracy. 2010. Short-term effects of experimental fires on a Mojave Desert seed bank. Journal of Arid Environments 74(10):1302-1308; (2) Esque,T.C., K.E. Nussear, K.K. Drake, A.D. Walde, K.H. Berry, R.C. Averill-Murray, A.P. Woodman, W.I. Boarman, P.A. Medica, J. Mack J.S. Heaton. In Press. Effects of Human Population Density, Resource Variability, and Subsidized Predators on Desert Tortoise Populations in the Mojave Desert. Endangered Species Research; (3) Esque, T.C, Esque, Jason P. Kaye, Sara E. Eckert, Lesley A. DeFalco, and C. Richard Tracy. 2010. Short-term soil inorganic N pulse after experimental fire alters invasive and native annual plant production in a Mojave Desert shrubland. Oecologia DOI:n10.1007/s00442-010-1617-1; (4) DeFalco, L.A., T.C. Esque, S.J. Scoles and J. Rodgers. 2010. Desert wildfire and severe drought diminish survivorship of the long-lived Joshua tree (Yucca brevifolia; Agavaceae). American Journal of Botany 97:243-350.

Kimball L. Garrett, Ornithology Collections Manager, Natural History Museum of Los Angeles County, Los Angeles, California. Garrett is an ornithologist with over 40 years of field experience in southern California and has worked widely throughout the southern California deserts. He obtained his undergraduate degree in Zoology from UC Berkeley and did graduate work in ornithology at UCLA. Since 1982 he has managed the extensive bird collections of the Natural History Museum of Los Angeles County. He co-authored *Birds of Southern California: Status and Distribution*, a standard work for the region published in 1981, along with the *Peterson Field Guide to Warblers of North America* (1997). He has co-edited the Southern California region for the avian distributional journal *North American Birds* since 2000. Garrett's research involves various aspects of bird distribution and seasonal status in southwestern North America, along with the ecology and population trends of non-native bird species in the region.

Dr. Christine A. Howell, Senior Conservation Scientist, PRBO Conservation Science, Petaluma, California. She has degrees from the University of California Berkeley (B.A. Biology 1991) and the University of Missouri Columbia (PhD Ecology 1999). Her doctoral research focused on avian demography and life history evolution. In 2000 she received a

National Science Foundation Post-doctoral Fellowship in Biological Informatics to pursue research in collaboration with Missouri Botanical Garden and the International Center for Tropical Ecology at the University of Missouri Saint Louis. Her NSF research focused on the development and use of spatially explicit models and statistics as practical tools in coarse-grain conservation studies. In 2004 she joined the staff of PRBO (formerly known as the Point Reyes Bird Observatory) as a Senior Conservation Scientist. Her research at PRBO has included projected climate change impacts on California's avifauna, wildlife responses to restoration, conservation of riparian obligate bird species, and riparian restoration design. She is currently editing a book on climate change adaptation case studies for California.

Robin Kobaly, Executive Director, The SummerTree Institute, Morongo Valley, California. Kobaly is a botanist and plant ecologist with expertise in plant communities in the Mojave and Sonoran deserts. She has degrees from the University of California at Riverside (B.A. Biology 1974 and M.A. Plant Ecology 1977), and 33 years' experience in plant ecology, wildlife biology, land use management, aerial photo interpretation, and natural history interpretation. She served as a botanist for the U.S. Bureau of Land Management for 21 years, working on regional conservation plans, habitat management plans, management plans for Areas of Critical Environmental Concern, and environmental impact statements. Kobaly has interpreted aerial photography to determine plant species composition, cover, biomass, and productivity desert-wide in California, and integrated satellite imagery, aerial photography, and ground data to help produce the vegetation map for the California Desert Conservation Area. Kobaly has worked with NASA's Jet Propulsion Laboratory to train scientists from NASA and BLM in new techniques for vegetation/soils mapping. She has conducted inventories and monitored impacts to rare, threatened, and endangered plant species, and resolved conflicts between resource protection and human activities within "Watchable Wildlife Areas", wildlife preserves, and Areas of Critical Environmental Concern.

Dr. Reed Noss, Professor, Department of Biology, University of Central Florida, Orlando, Florida. Dr. Noss, an internationally known conservation biologist with special expertise in landscape ecology, land use planning, ecosystem management, and reserve design. He recently started a new conservation biology graduate program at the University of Central Florida. He has a particular interest in translating the principles of conservation biology to policy and management, and was first author of the book *The Science of Conservation Planning*. Dr. Noss has served as a member and as lead scientist on numerous scientific advisory committees, including those for several other NCCP/HCPs. He has served both as President of the Society for Conservation Biology and as Editor-in-Chief of its journal, *Conservation Biology*.

Dr. Richard Redak, Professor of Entomology and Department Chair, College of Natural and Agricultural Sciences, UC Riverside. Dr. Rekak's research is directed toward understanding the interactions between insect herbivores and their host plants and involves understanding the impacts that both host-plant and insect herbivore have upon one another. Such research involves investigating individual plant-insect interactions to community level processes. This involves determining the roles that plant attributes (plant defensive mechanisms, phenology, spatial distribution) have in influencing insect herbivore host-plant selection, feeding, growth, development, reproduction, and ultimately fitness and species distribution. Additionally, studies of plant-insect interactions must take into account the effects of insect herbivory upon host-plant populations under a variety of different environmental conditions. This includes not only

estimating the impact of insect herbivory upon individual host plants (e.g. estimates of defoliation, leaf-loss, altered plant fitness and distribution, economic losses to crops where applicable) but also includes determining how these impacts are affected by changes in the biotic and abiotic environment of the plant and insect herbivore. As UCR is located at the 3-way interface between 1) one of the world's major urban centers, 2) major agricultural production areas, and 3) unique coastal, mountain, and desert ecosystems, we are provided with a unique opportunity to investigate the interactions between plants and insect herbivores within within all 3 types of areas and their interfaces. From an applied perspective this includes studies of phytophagous insects found in ornamental, floricultural, nursery, landscape and turfgrass plants as well as determining the impact of urbanization on native plant-insect associations. Such studies include the direct and indirect effects of air and water anthropogenic pollutants (CO2, ozone, acidic and particulate precipitation, use of run-off water), as well as other environmental stresses (e.g. habitat loss) upon plant-insect interactions. Currently, we are undertaking studies investigating 1) the use of whole insect communities to assess community recovery following fire or restoration, 2) the impact of land management practices on insect community structure 3) the importance of insect community structure and biomass distribution in determining the habitat quality of endangered species of vertebrate insectivores, 4) integrated pest management approaches directed toward controlling the glassy-winged sharpshooter, and 5) the host-plant selection and utilization by floricultural insect pests.

Dr. Wayne D. Spencer, Senior Conservation Biologist, Conservation Biology Institute, San Diego. Dr. Spencer is a conservation biologist and wildlife ecologist with expertise in conservation planning and endangered species recovery. He has worked on various regional NCCPs and HCPs in California as a consulting biologist, science advisor, and science facilitator, and has been involved in habitat connectivity planning and wildlife movement studies throughout California and the western U.S. His field research focuses primarily on rare and endangered mammal species, including the endangered Stephens' kangaroo rat and Pacific pocket mouse. He is also a Research Associate with the San Diego Natural History Museum.

Dr. Robert H. Webb, Research Hydrologist, U.S. Geological Survey, Tucson, Arizona. Dr. Webb has worked on long-term changes in natural ecosystems of the southwestern United States since 1976. He has degrees in engineering (B.S., University of Redlands, 1978), environmental earth sciences (M.S., Stanford University, 1980), and geosciences (Ph.D, University of Arizona, 1985). His dissertation concerned late Holocene and historical flooding of the Escalante River within Grand Staircase – Escalante National Monument and the relation of that flooding with arroyo downcutting. Since 1985, he has been a research hydrologist with the U.S. Geological Survey in Tucson and an adjunct faculty member of the Departments of Geosciences and Hydrology and Water Resources at the University of Arizona. Dr. Webb does interdisciplinary work merging history, climate change, desert vegetation ecology, hydrology, geomorphology, and Quaternary geology to attempt to understand long-term change in the desert regions of the United States and Mexico. He has authored or edited 13 books, including *Environmental Effects of Off-Road Vehicles* (with Howard Wilshire); *Grand Canyon, A Century of Change*; *Floods, Droughts, and Changing Climates* (with Michael Collier); *The Changing Mile Revisited* (with Raymond Turner); *Cataract Canyon: A Human and Environmental History of the Rivers in Canyonlands* (with Jayne Belnap and John Weisheit); *The Ribbon of Green* (with Stanley A. Leake and Turner), the *Mojave Desert: Ecosystem Processes and Sustainability* (with 5 other

editors); and, most recently, *Repeat Photography: Methods and Applications in the Natural Sciences* (with Diane E. Boyer and Turner).

Theodore J. Weller, Ecologist, USDA Forest Service, Pacific Southwest Research Station, Arcata, California. Mr. Weller has worked with bats since 1996 and has published 10 papers on them in the peer-reviewed scientific literature. His research has focused largely on methodological issues and survey effort necessary to describe bat activity, characterize species assemblages, and monitor their population status at multiple spatial scales. More recently, his attention has turned toward documenting impacts and devising solutions to problems of bat fatalities at wind energy facilities in California. He has conducted research at 2 wind energy facilities within the DRECP planning area where he is applying multiple echolocation monitoring tools to characterize bat activity levels and develop predictive models of bat activity at wind energy facilities. He is a member of the Bats and Wind Energy Cooperative and serves as an Independent Science Advisor to the Altamont Pass Wind Resource Area NCCP..

Appendix B

Draft Vegetation Alliance List for DRECP Region

(includes slopes of adjacent ecoregions as defined in boundary area in DRECP draft document)

Draft June 14, 2010
Vegetation Classification and Mapping Program
California Department of Fish and Game
Biogeographic Data Branch

Class 1. Mesomorphic Tree Vegetation (Forest and Woodland)
- Subclass 1.C. Temperate Forest
  - Formation 1.C.1. Warm Temperate Forest
    - Division 1.C.1.c. Madrean Forest and Woodland
      - Macrogroup MG009. California Forest and Woodland
        - Group - Californian broadleaf forest and woodland
          - *Aesculus californica* Alliance
          - *Quercus chrysolepis* (tree) Alliance
          - *Quercus douglasii* Alliance
          - *Quercus kelloggii* Alliance
          - *Quercus lobata* Alliance
          - *Umbellularia californica* Alliance
        - Group - Californian evergreen coniferous forest and woodland
          - *Callitropsis nevadensis* Alliance
          - *Juniperus californica* Alliance
          - *Pinus attenuata* Alliance
          - *Pinus coulteri* Alliance
          - *Pinus quadrifolia* Alliance
          - *Pinus sabiniana* Alliance

  - Formation 1.C.2. Cool Temperate Forest
    - Division 1.C.2.b. Western North America Cool Temperate Forest
      - Macrogroup MG023. Californian–Vancouverian Montane and Foothill Forest
        - Group - Californian montane conifer forest
          - *Abies concolor* Alliance
          - *Abies concolor–Pinus lambertiana* Alliance
          - *Abies magnifica–Abies concolor* Alliance
          - *Pinus jeffreyi* Alliance
          - *Pinus ponderosa* Alliance

Pinus ponderosa–Calocedrus decurrens Alliance
Pseudotsuga macrocarpa Alliance

Macrogroup MG020. Rocky Mountain Subalpine and High Montane Conifer Forest
Group - Rocky Mountain mesic subalpine forest and woodland
Populus tremuloides Alliance
Group - Western Cordilleran xeric subalpine coniferous forest and woodland
Pinus albicaulis Alliance
Pinus balfouriana Alliance
Pinus flexilis Alliance
Pinus longaeva Alliance

Macrogroup MG025. Vancouverian Subalpine Forest
Group - Vancouverian mesic montane coniferous forest and woodland
Abies magnifica Alliance
Pinus contorta ssp. *murrayana* Alliance
Pinus monticola Alliance
Tsuga mertensiana Alliance

Division 1.C.2.c. North American Intermountain Basins Scrub Woodland
Macrogroup MG026. Intermountain Basins Pinyon–Juniper Woodland
Group - Western Great Basin montane conifer woodland
Juniperus grandis Alliance
Juniperus occidentalis Alliance
Juniperus osteosperma Alliance
Pinus edulis Special Stands
Pinus monophylla Alliance

Division 1.C.2.x. North American Introduced Evergreen Broadleaf and Conifer Forest
Macrogroup MG027. Introduced North American Mediterranean woodland and forest
Group - [No subdivision at group level]
Eucalyptus (*camaldulensis, globulus*) Semi-natural Stands
Schinus (*molle*)–*Myoporum laetum* Semi-natural Stands

Formation 1.C.3. Temperate Flooded and Swamp Forest
Division 1.C.3.b Western North America Flooded and Swamp Forest

Macrogroup MG031. Western cool temperate scrub swamp

Group - Western dogwood thicket

Cornus sericea Alliance

Macrogroup MG034. Western Cordilleran montane–boreal riparian scrub and forest

Group - Great Basin montane riparian scrub

Betula occidentalis Alliance
Rosa woodsii Provisional Alliance
Salix lutea Alliance

Group - Western North American montane–subalpine riparian scrub

Acer glabrum Provisional Alliance
Alnus incana Alliance
Dasiphora fruticosa Alliance
Salix bebbiana Alliance
Salix eastwoodiae Alliance
Salix geyeriana Alliance
Salix jepsonii Alliance
Salix lemmonii Alliance
Salix orestera Alliance
Salix planifolia Provisional Alliance

Group - Vancouverian riparian deciduous forest

Alnus rhombifolia Alliance
Fraxinus latifolia Alliance
Populus trichocarpa Alliance
Salix lucida Alliance

Division 1.C.3.c Western North America Warm Temperate Flooded and Swamp Forest

Macrogroup MG036. Southwestern North American Riparian, Flooded and Swamp Forest/Scrubland

Group - Southwestern North American riparian evergreen and deciduous woodland

Acer negundo Alliance
Platanus racemosa Alliance
Populus fremontii Alliance
Salix gooddingii Alliance
Salix laevigata Alliance
Washingtonia filifera Alliance

Group - Southwestern North American riparian/wash scrub

Baccharis emoryi Provisional Alliance
Baccharis salicifolia Alliance

Baccharis sergiloides Alliance
Forestiera pubescens Alliance
Rosa californica Alliance
Salix exigua Alliance
Salix lasiolepis Alliance
Sambucus nigra Alliance

Group - Southwestern North American introduced riparian scrub
Arundo donax Semi-natural Stands
Tamarix spp. Semi-natural Stands

Class 2. Mesomorphic Shrub and Herb Vegetation (Shrubland and Grassland)
Sub-Class 2.B. Mediterranean Scrub and Grassland
Formation 2.B.1. Mediterranean Scrub
Division 2.B.1.a. California Scrub
Macrogroup MG043. California Chaparral
Group - Californian xeric chaparral
Adenostoma fasciculatum Alliance
Adenostoma fasciculatum–Salvia apiana Alliance
Adenostoma fasciculatum–Salvia mellifera Alliance
Arctostaphylos glauca Alliance
Ceanothus cuneatus Alliance
Eriodictyon californicum Alliance
Eriodictyon crassifolium Provisional Alliance

Group - Californian mesic chaparral
Cercocarpus montanus Alliance
Prunus ilicifolia Alliance
Quercus berberidifolia Alliance
Quercus berberidifolia–Adenostoma fasciculatum Alliance

Group - Californian pre-montane chaparral
Arctostaphylos glandulosa Alliance
Arctostaphylos pringlei ssp. *drupacea* Alliance
Ceanothus leucodermis Alliance
Ceanothus oliganthus Alliance
Quercus chrysolepis (shrub) Alliance
Quercus wislizeni (shrub) Alliance

Macrogroup MG044. California Coastal Scrub
Group - Central and South Coastal Californian coastal sage scrub
Eriogonum fasciculatum Alliance

Eriogonum fasciculatum–Salvia apiana Alliance
Eriogonum heermannii Provisional Alliance
Eriogonum wrightii Alliance
Keckiella antirrhinoides Alliance
Salvia apiana Alliance
Salvia mellifera Alliance

Group - Central and south coastal California seral scrub
Dendromecon rigida Alliance
Ericameria linearifolia Provisional Alliance
Ericameria palmeri Provisional Alliance
Gutierrezia californica Provisional Alliance
Hazardia squarrosa Alliance
Lotus scoparius Alliance
Lupinus albifrons Alliance
Malacothamnus fasciculatus Alliance

Group - Naturalized non-native Mediterranean scrub
Broom (*Cytisus scoparius* and others) Semi-natural Stands

Formation 2.B.2. Mediterranean Grassland and Forb Meadow
Division 2.B.2.a. California Grassland and Meadow
Macrogroup MG045. California Annual and Perennial Grassland
Group - California annual forb/grass vegetation
Ambrosia psilostachya Provisional Alliance
Amsinckia (*menziesii, tessellata*) Alliance
Artemisia dracunculus Alliance
Eschscholzia (*californica*) Alliance
Lasthenia californica–Plantago erecta–Vulpia microstachys Alliance
Lotus purshianus Provisional Alliance
Plagiobothrys nothofulvus Alliance

Group - California perennial grassland
Nassella cernua Provisional Alliance
Nassella lepida Provisional Alliance
Nassella pulchra Alliance

Group - Mediterranean California naturalized annual and perennial grassland
Aegilops triuncialis Semi-natural Stands
Avena (*barbata, fatua*) Semi-natural Stands
Brassica (nigra) and other mustards Semi-natural Stands

Bromus (*diandrus, hordeaceus*)–*Brachypodium distachyon*
Semi-natural Stands
Bromus rubens–Schismus (*arabicus, barbatus*) Semi-natural Stands
Centaurea (*solstitialis, melitensis*) Semi-natural Stands
Centaurea (*virgata*) Semi-natural Stands
Lolium perenne Semi-natural Stands
Pennisetum setaceum Semi-natural Stands

Subclass 2.C. Temperate and Boreal Shrubland and Grassland
Formation 2.C.1. Temperate Grassland, Meadow, and Shrubland
Division 2.C.1.a. Vancouverian and Rocky Mountain Grassland and Shrubland
Macrogroup MG047. Western Cordilleran montane-boreal wet meadow
Group - Western Cordilleran montane-boreal summer-drying wet meadow
Carex douglasii Provisional Alliance
Iris missouriensis Provisional Alliance
Muhlenbergia filiformis Provisional Alliance
Veratrum californicum Alliance

Group - Western cordilleran montane-boreal mesic wet meadow
Carex heteroneura Provisional Alliance
Carex integra Provisional Alliance
Carex jonesii Alliance
Carex lasiocarpa Provisional Alliance
Carex microptera Provisional Alliance
Carex nebrascensis Alliance
Carex straminiformis Provisional Alliance
Carex subnigricans Alliance
Deschampsia caespitosa Alliance
Juncus nevadensis Alliance
Solidago canadensis Provisional Alliance
Trifolium longipes Provisional Alliance

Macrogroup MG048. Western North American Temperate Grassland and Meadow
Group - Western dry upland perennial grassland
Aristida purpurea Provisional Alliance
Elymus glaucus Alliance
Elymus multisetus Provisional Alliance

Leymus cinereus Alliance
Poa secunda Alliance

Group - Vancouverian and Rocky Mountain naturalized perennial grassland
Agrostis (stolonifera, gigantea)-Festuca arundinacea Semi-natural Stands
Holcus lanatus-Anthoxanthum odoratum Semi-natural Stands
Phalaris aquatica Semi-natural Stands
Poa pratensis Semi-natural Stands

Group - Vancouverian and Rocky Mountain naturalized annual grassland
Bromus tectorum Semi-natural Stands

Macrogroup MG049. Western Cordilleran Montane Shrubland and Grassland

Group - Western Cordilleran montane moist graminoid meadow
Calamagrostis canadensis Alliance
Cistanthe (*umbellata*)–*Gayophytum* (*diffusum*) Alliance
Danthonia intermedia Provisional Alliance
Hordeum brachyantherum Alliance
Muhlenbergia richardsonis Provisional Alliance
Penstemon heterodoxus Provisional Alliance
Ptilagrostis kingii Alliance

Group - Sierran montane rock crevice and outcrop scrub and herbaceous
Holodiscus discolor Alliance
Juncus parryi Alliance
Penstemon newberryi Alliance
Phyllodoce breweri Alliance

Group - Southern Vancouverian montane deciduous scrub
Ceanothus integerrimus Alliance
Prunus emarginata Provisional Alliance
Quercus garryana Shrub Alliance

Group - Western Cordilleran montane deciduous scrub
Artemisia cana Alliance
Prunus virginiana Provisional Alliance
Rhus trilobata Provisional Alliance
Ribes quercetorum Provisional Alliance

Macrogroup MG050. Vancouverian Lowland Grassland and Shrubland

Group - Naturalized non-native deciduous scrub
Rubus armeniacus Semi-natural Stands

Division 2.C.1.x. Western North America Interior Sclerophyllous Shrubland

Macrogroup MG051. Warm Interior Chaparral

Group - Western Mojave and Western Sonoran Desert borderland chaparral
Adenostoma sparsifolium Alliance
Quercus cornelius-mulleri Alliance
Quercus john-tuckeri Alliance
Quercus palmeri Alliance

Group - Mogollion Rim chaparral
Ceanothus greggii Alliance
Quercus turbinella Alliance
Rhus ovata Alliance

Macrogroup MG052. Western North American Cool/Montane Sclerophyllous Evergreen Scrub

Group - Californian montane chaparral
Ceanothus cordulatus Alliance
Chrysolepis sempervirens Alliance
Quercus vacciniifolia Alliance

Group - Western Cordilleran montane sclerophyll scrub
Arctostaphylos patula Alliance
Ceanothus velutinus Alliance

Formation 2.C.4. Temperate and Boreal Bog and Fen*

Division 2.C.4.a. North American Scrub and Herb Peatland

Macrogroup MG063. Western North American Montane/Boreal Peatland

Group - [No group subdivision]
Carex limosa Alliance
Carex luzulina Provisional Alliance
Dulichium arundinaceum Provisional Alliance
Rhododendron neoglandulosum Alliance
Vaccinium uliginosum Alliance

Formation 2.C.5. Temperate and Boreal Freshwater Marsh

Division 2.C.5.b. Western North American Freshwater Marsh

Macrogroup MG073. Western North American Freshwater Marsh

Group - Arid West freshwater emergent marsh

Phragmites australis Alliance
Schoenoplectus acutus Alliance
Schoenoplectus californicus Alliance
Typha (*angustifolia, domingensis, latifolia*) Alliance

Macrogroup MG074. Western North America Vernal Pool

Group - Californian mixed annual/perennial freshwater vernal pool/swale/plain bottomland

Alopecurus geniculatus Provisional Alliance
Lasthenia fremontii–Downingia (*bicornuta*) Alliance
Eleocharis macrostachya Alliance
Eleocharis acicularis Alliance
Grindelia (*stricta*) Provisional Alliance
Centromadia (*pungens*) Alliance
Deinandra fasciculata Alliance

Macrogroup MG075. Western North America Wet Meadow and Low Shrub Carr

Group - Western Cordilleran montane-boreal summer-saturated meadow

Bistorta bistortoides–Mimulus primuloides Alliance
Camassia quamash Alliance
Carex (*aquatilis, lenticularis*) Alliance
Carex nigricans Provisional Alliance
Carex scopulorum Alliance
Carex simulata Alliance
Carex (utriculata, vesicaria) Alliance
Eleocharis quinqueflora Alliance
Glyceria (*elata, striata*) Alliance
Glyceria occidentalis Provisional Alliance
Oxypolis occidentalis Alliance
Senecio triangularis Alliance
Torreyochloa pallida Alliance

Group - Californian warm temperate marsh/seep

Carex barbarae Alliance
Carex densa Provisional Alliance
Carex nudata Alliance
Juncus arcticus (var. *balticus, mexicana*) Alliance
Juncus (*oxymeris, xiphioides*) Provisional Alliance
Leymus triticoides Alliance
Mimulus (guttatus) Alliance
Muhlenbergia rigens Alliance

Group - Naturalized warm-temperate riparian and wetland group

Lepidium latifolium Semi-natural Stands
Persicaria lapathifolia–Xanthium strumarium Provisional Alliance

Formation 2.C.6. Temperate and Boreal Salt Marsh

Division 2.C.6.c Temperate and Boreal Pacific Coastal Salt Marsh

Macrogroup MG081. North American Pacific Coastal Salt Marsh

Group - Temperate Pacific tidal salt and brackish meadow

Bolboschoenus maritimus Alliance
Distichlis spicata Alliance

Group - Western North American disturbed alkaline marsh and meadow

Sesuvium verrucosum Alliance
Atriplex prostrata–Cotula coronopifolia Semi-natural Stands

Division 2.C.6.d Western North American Interior Alkali–Saline Wetland

Macrogroup MG082. Cool Semi-Desert Alkali–Saline Wetlands

Group - Great Basin cool semi-desert alkali basin

Sarcobatus vermiculatus Alliance

Macrogroup MG083. Warm Semi-Desert/Mediterranean Alkali–Saline Wetland

Group - Southwestern North American alkali marsh/seep vegetation

Anemopsis californica Alliance
Juncus cooperi Alliance
Schoenoplectus americanus Alliance
Spartina gracilis Alliance
Sporobolus airoides Alliance

Group - Southwestern North American salt basin and high marsh

Allenrolfea occidentalis Alliance
Arthrocnemum subterminale Alliance
Atriplex lentiformis Alliance
Atriplex spinifera Alliance
Cressa truxillensis–Distichlis spicata Alliance
Frankenia salina Alliance
Suaeda moquinii Alliance

Class 3. Xeromorphic Scrub and Herb Vegetation (Semi-Desert)

Subclass 3.A. Warm Semi-Desert Scrub and Grassland

Formation 3.A.1. Warm Semi-Desert Scrub and Grassland

Division 3.A.1.a Sonoran and Chihuahuan Semi-Desert Scrub and Grassland

Macrogroup MG088. Mojavean–Sonoran Desert Scrub

Group - Lower Bajada and Fan Mojavean–Sonoran desert scrub

Ambrosia dumosa Alliance
Ambrosia salsola Alliance
Atriplex polycarpa Alliance
Encelia farinosa Alliance
Larrea tridentata Alliance
Larrea tridentata–Ambrosia dumosa Alliance
Larrea tridentata–Encelia farinosa Alliance
Cylindropuntia bigelovii Alliance
Pleuraphis rigida Alliance
Tidestromia oblongifolia Provisional Alliance

Group - Arizonan upland Sonoran desert scrub

Parkinsonia microphylla Provisional Alliance
Prunus fremontii Alliance
Simmondsia chinensis Provisional Alliance
Tetracoccus hallii Provisional Alliance
Viguiera parishii Alliance
Ziziphus obtusifolia Special Stands

Group - Mojavean upper desert scrub

Menodora spinescens Alliance
Salazaria mexicana Alliance
Yucca brevifolia Alliance
Yucca schidigera Alliance

Macrogroup MG089. Viscaino–Baja California Desert Scrub

Group - Baja California del Norte Gulf Coast–ocotillo–limberbush–creosote bush desert scrub

Bursera microphylla Special Stands

Macrogroup MG092. Madrean Warm Semi-Desert Wash Woodland/Scrub

Group - Mojavean semi-desert wash scrub

Acacia greggii Alliance
Ephedra californica Alliance
Ericameria paniculata Alliance
Lepidospartum squamatum Alliance
Prunus fasciculata Alliance

Viguiera reticulata Alliance

Group - Sonoran-Coloradan semi-desert wash woodland/scrub

Agave deserti Alliance
Castela emoryi Special Stands
Chilopsis linearis Alliance
Hyptis emoryi Alliance
Justicia californica Provisional Alliance
Koeberlinia spinosa Special Stands
Parkinsonia florida–Olneya tesota Alliance
Pluchea sericea Alliance
Prosopis glandulosa Alliance
Prosopis pubescens Alliance
Psorothamnus spinosus Alliance

Subclass 3.B. Cool Semi-Desert Scrub and Grassland

Formation 3.B.1. Cool Semi-Desert Scrub and Grassland

Division 3.B.1.a. Western North American Cool Semi-Desert Scrub and Grassland

Macrogroup MG093. Western North American Cool Semi-Desert Shrubland, Shrub-Steppe

Group - Shadscale-saltbush cool semi-desert scrub

Atriplex confertifolia Alliance
Atriplex canescens Alliance

Macrogroup MG095. Cool Semi-desert wash and disturbance scrub

Group - Intermontane seral shrubland

Encelia virginensis Alliance
Ericameria nauseosa Alliance
Ericameria parryi Alliance
Ericameria teretifolia Alliance
Gutierrezia sarothrae Provisional Alliance
Salvia dorrii Alliance

Macrogroup MG096. Western North America Tall Sage Shrubland and Steppe

Group - Inter-Mountain West mesic tall sagebrush shrubland and steppe

Artemisia rothrockii Alliance
Artemisia tridentata Alliance
Artemisia tridentata ssp. *vaseyana* Alliance

Macrogroup MG097. Western North America Dwarf Sage Shrubland and Steppe

Group - Intermountain low sage shrubland and steppe
Artemisia arbuscula ssp. *arbuscula* Alliance
Artemisia arbuscula ssp. *longicaulis* Provisional Alliance
Artemisia nova Alliance

Macrogroup MG098. Inter-Mountain Dry Shrubland and Grassland
Group - Intermontane deep or well-drained soil scrub
Ephedra nevadensis Alliance
Ephedra viridis Alliance
Grayia spinosa Alliance
Krascheninnikovia lanata Alliance
Lycium andersonii Alliance

Group - Intermountain shallow/calcareous soil scrub
Cercocarpus intricatus Alliance
Cercocarpus ledifolius Alliance
Coleogyne ramosissima Alliance
Nolina (bigelovii, parryi) Alliance
Purshia stansburiana Alliance
Purshia tridentata Alliance

Group - Northern Great Basin semi-desert grassland group
Achnatherum hymenoides Alliance
Pseudoroegneria spicata Alliance
Agropyron cristatum Semi-natural Stands

Group - Southern Great Basin semi-desert grassland group
Achnatherum speciosum Alliance
Pleuraphis jamesii Alliance

Class 4. Cryomorphic Shrub and Herb Vegetation (Polar and High Montane Vegetation)
Subclass 4.B. Temperate and Boreal Alpine Vegetation
Fomation 4.B.1. Alpine Scrub, Forb Meadow, and Grassland
Division 4.B.1.b Western North America Alpine Scrub, Forb Meadow, and Grassland
Macrogroup MG099. Rocky Mountain Alpine Scrub, Forb Meadow, and Grassland
Group - Rocky Mountain alpine turf
Kobresia myosuroides Alliance
Salix nivalis Provisional Alliance
Salix petrophila Alliance

Macrogroup MG101. Vancouverian Alpine Scrub, Forb Meadow, and Grassland

Group - Californian alpine–subalpine turf
Calamagrostis muiriana Alliance
Carex breweri Alliance
Carex filifolia Alliance
Festuca brachyphylla Alliance
Kalmia microphylla Alliance
Vaccinium cespitosum Alliance

Group - Vancouverian snowbank turf
Carex helleri Alliance
Carex spectabilis Alliance
Cassiope mertensiana Provisional Alliance
Saxifraga nidifica Provisional Alliance
Saxifraga tolmiei Provisional Alliance

Group - Mediterranean California alpine fell-field
Calamagrostis purpurascens Alliance
Carex congdonii Provisional Alliance
Ericameria discoidea–Hulsea algida Alliance
Oxyria digyna Provisional Alliance
Phlox covillei Alliance
Phlox pulvinata Alliance

Class 5. Hydromorphic Vegetation (Aquatic Vegetation)
Subclass 5.A. Saltwater Aquatic Vegetation
Formation 5.A.1. Marine and Estuarine Saltwater Aquatic Vegetation
Division 5.A.1.c. Temperate Pacific Saltwater Aquatic Vegetation
Macrogroup MG106. Temperate Pacific Intertidal Shore
Group - Temperate Pacific intertidal flat
Stuckenia (*pectinata*)–*Potamogeton* spp. Alliance

Subclass 5.B. Freshwater Aquatic Vegetation
Formation 5.B.1. Freshwater Aquatic Vegetation
Division 5.B.1.a North American Freshwater Aquatic Vegetation
Macrogroup MG109. Western North American Freshwater Aquatic Vegetation
Group - Temperate Pacific freshwater aquatic bed
Isoetes spp. Provisional Alliance
Nuphar lutea Provisional Alliance
Sparganium (*angustifolium*) Alliance

Group - Temperate freshwater floating mat
Azolla (*filiculoides, mexicana*) Provisional Alliance
Lemna (minor) and relatives Provisional Alliance

Group - Naturalized temperate Pacific freshwater vegetation

Ludwigia (*hexapetala, peploides*) Semi-natural Stands

Class 6 Lithomorphic Vegetation (Nonvascular and Sparse Vascular Rock Vegetation)

Subclass 6.B. Mediterranean, Temperate, and Boreal Nonvascular and Sparse Vegetation

Formation 6.B.1. Mediterranean Cliff, Scree, and Rock Vegetation

Division 6.B.1.a. North American Mediterranean Rock Outcrop, Scree, and Talus Nonvascular and Sparse Vascular Vegetation

Macrogroup MG110. California Cliff, Scree, and Other Rock Vegetation

Group - Central California Coast Ranges cliff and canyon

Sedum spathulatum Provisional Alliance

Selaginella bigelovii Alliance

Division 6.B.2.b. Western North America Temperate Cliff, Scree, and other Rock Vegetation

Macrogroup MG114. Vancouverian Cliff, Scree, and Other Rock Vegetation

Group - Sierra Nevada cliff and canyon

Subclass 6.C Semi-Desert Nonvascular and Sparse Vascular Vegetation

Formation 6.C.1 Warm Semi-Desert Cliff, Scree, and Rock Vegetation

Division 6.C.1.a North American Warm Semi-Desert Cliff, Scree, and Rock Vegetation

Macrogroup MG117. North American Warm Semi-Desert Cliff, Scree, and Other Rock Vegetation

Group - North American warm desert dunes and sand flats

Dicoria canescens–Abronia villosa Alliance

Panicum urvilleanum Alliance

Swallenia alexandrae Special Stands

Group - North American warm desert bedrock cliff and outcrop

Atriplex hymenelytra Alliance

Ephedra funerea Provisional Alliance

Appendix C

Individuals with Known Expertise Regarding Sensitive Invertebrates in the DRECP Planning Area

Name	Affiliation	Contact Information	Expertise
Dr. Doug Yanega	Dept. Entomology, University of California, Riverside, CA 92521	Douglas.yanega@ucr.edu	Insects, Hymenoptera *and able to direct inquiries to other museum staff*
Dr. Lynn Kimsey	Professor and Curator, Bohort Entomology Museum. Dept. Entomology, University of California, Davis, CA, 95616	lskimsey@ucdavis.edu	Insects especially on dunes, *and able to direct inquiries to other museum staff*
Dr. William Wiesenborn	US Bureau of Reclamation, P.O. Box 61470, Boulder City, NV 89006		Gastropods, Insects
Dr. Rosemary Gillespie	Director, UCB Essig Museum, Essig Museum of Entomology University of California, Berkeley, CA 94720	Gillespie@berkeley.edu	Insects, Arachnids, *and able to direct inquiries to other museum staff*
Dr. Michael Wall	Curator of Entomology, San Diego Natural History Museum, P.O Box 121390, San Diego, CA 92112	mwall@sdnhm.org	Insects, *and able to direct inquiries to other museum staff*
Dr. Gordon Pratt	Dept. Entomology, University of California, Riverside, CA 92521	Gordon.pratt@ucr.edu	Insects, Lepidoptera
Dr. Travis Longcore	Dept. Geography, University of Southern California, Los Angeles, CA 90089	longcore@usc.edu	Insects, Lepidoptera, Diptera, Coleoptera

Name	Affiliation	Contact Information	Expertise
Dr. Dave Kavanaugh	Chair and Curator, Dept of Entomology, California Academy of Sciences	dkavanaugh@calacademy.org 415-379-5315	Insects, Coleoptera *and able to direct inquiries to other museum staff*
Dr. Joel Martin	Curator of Crustacea and Chair of Invertebrate Studies, Natural History Museum of Los Angeles, Los Angeles CA	213-763-3466	Crustacea *and able to direct inquiries to other museum staff*
Dr. Brian Brown	Curator of Entomology, Natural History Museum of Los Angeles,	213-763-3466	Insects, Diptera
Dr. Michael Fugate	Dept. Biology, University of California, Riverside, CA 92516	Michael.Fugate@ucr.edu 951-8272647	Crustaceans (fairy shrimp)
Mr. David Hawks	Dept. Entomology University of California, Riverside, CA 92516	David.hawks@ucr.edu	Insects, beetles
Mr. Greg Ballmer	Dept. of Entomology, University of California, Riverside, CA 92516	ballmer@ucr.edu	Insects, Lepidoptera, Coleoptera
Mr. Thomas Prentice	Dept. Entomology, University of California, Riverside, CA 92516	Thomas.prentice@ucr.edu	Arachnids
Mr. Rick Vetter	Dept. Entomology, University of California, Riverside, CA 92516	Rick.vetter@ucr.edu	Arachnids
Mr. Jeremiah George	Dept. Entomology, University of California, Riverside, CA 92516	Georgj01@student.ucr.edu	Insects
Mr. Kendall Osborne	Osborne Consulting, 6675 Avenue Juan Diaz, Riverside, CA 92509	951-360-6461	Insects

Appendix D

CNPS List 1B & 2 Taxa in the DRECP Planning Area

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Abert's sanvitalia	*Sanvitalia abertii*	None	None	G5	S1S2	2.2
Abrams' spurge	*Chamaesyce abramsiana*	None	None	G4	S1.2	2.2
Algodones Dunes sunflower	*Helianthus niveus ssp. tephrodes*	None	Endangered	G4T2	S1.2	1B.2
Alkali mariposa-lily	*Calochortus striatus*	None	None	G2	S2	1B.2
Amargosa beardtongue	*Penstemon fruticiformis var. amargosae*	None	None	G4T3	S2.3	1B.3
Amargosa nitrophila	*Nitrophila mohavensis*	None	Endangered	G1	S1.1	1B.1
Angel trumpets	*Acleisanthes longiflora*	None	None	G5	S1.3	2.3
Annual rock-nettle	*Eucnide rupestris*	None	None	G3	S1	2.2
Appressed muhly	*Muhlenbergia appressa*	None	None	G4	S3?	2.2
Arizona cottontop	*Digitaria californica*	None	None	G5	S1.3	2.3
Arizona pholistoma	*Pholistoma auritum var. arizonicum*	None	None	G5T2T3	S1.3	2.3
Arizona spurge	*Chamaesyce arizonica*	None	None	G5	S1.3	2.3
Ash Meadows buckwheat	*Eriogonum contiguum*	None	None	G2?	S2?	2.3
Ash Meadows gumplant	*Grindelia fraxinipratensis*	None	None	G2	S1.2	1B.2
Ash-gray paintbrush	*Castilleja cinerea*	None	None	G2	S2.2	1B.2
Aven Nelson's phacelia	*Phacelia anelsonii*	None	None	G2G3	S2.3?	2.3
Baja California ipomopsis	*Ipomopsis effusa*	None	None	G3?	S1.1	2.1
Baja navarretia	*Navarretia peninsularis*	None	None	G3?	S2.2	1B.2
Bald daisy	*Erigeron calvus*	None	None	G1Q	S1.1	1B.1

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Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Baldwin Lake linanthus	*Linanthus killipii*	None	None	G2	S2.1	1B.2
Bare-stem larkspur	*Delphinium scaposum*	None	None	G5	S1.3	2.3
Barneby's phacelia	*Phacelia barnebyana*	None	None	G3?	S2.3	2.3
Barstow woolly sunflower	*Eriophyllum mohavense*	None	None	G2	S2.2	1B.2
Bear Valley pyrrocoma	*Pyrrocoma uniflora var. gossypina*	None	None	G5T2	S2.2	1B.2
Big Bear Valley milk-vetch	*Astragalus lentiginosus var. sierrae*	None	None	G5T1	S1?	1B.2
Big Bear Valley phlox	*Phlox dolichantha*	None	None	G2	S2.2	1B.2
Big Bear Valley sandwort	*Arenaria ursina*	None	None	G2	S2.1	1B.2
Big Bear Valley woollypod	*Astragalus leucolobus*	None	None	G2	S2.2	1B.2
Bird-foot checkerbloom	*Sidalcea pedata*	None	Endangered	G1	S1.1	1B.1
Bitter hymenoxys	*Hymenoxys odorata*	None	None	G5	S2	2
Black bog-rush	*Schoenus nigricans*	None	None	G4	S2.2	2.2
Black milk-vetch	*Astragalus funereus*	None	None	G2	S2.2	1B.2
Booth's evening-primrose	*Camissonia boothii ssp. boothii*	None	None	G5T4	S2.3	2.3
Booth's hairy evening-primrose	*Camissonia boothii ssp. intermedia*	None	None	G5T3T4	S2.3	2.3
Breedlove's buckwheat	*Eriogonum breedlovei var. breedlovei*	None	None	G3T2	S2.2	1B.2
Bristly scaleseed	*Spermolepis echinata*	None	None	G5	S1.3	2.3
Brown fox sedge	*Carex vulpinoidea*	None	None	G5	S2.2	2.2
Brown turbans	*Malperia tenuis*	None	None	G4?	S1.3	2.3
Burro grass	*Scleropogon brevifolius*	None	None	G5	S1.3	2.3
Calico monkeyflower	*Mimulus pictus*	None	None	G2	S2.2	1B.2
California ayenia	*Ayenia compacta*	None	None	G4	S3.3	2.3
California dandelion	*Taraxacum californicum*	None	None	G2	S2.1	1B.1

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Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
California marina	*Marina orcuttii var. orcuttii*	None	None	G2G3T1T2	S1.3	1B.3
California satintail	*Imperata brevifolia*	None	None	G2	S2.1	2.1
California saw-grass	*Cladium californicum*	None	None	G4	S2.2	2.2
Cave evening-primrose	*Oenothera cavernae*	Endangered	None	G2G3	S1	2.1
Chambers' physaria	*Physaria chambersii*	None	None	G4	S2.3	2.3
Chaparral sand-verbena	*Abronia villosa var. aurita*	Endanagered	None	G5T3T4	S2.1	1B.1
Charleston sandwort	*Arenaria congesta var. charlestonensis*	None	None	G5T2?	S1.3	1B.3
Charlotte's phacelia	*Phacelia nashiana*	None	None	G3	S3.2	1B.2
Cima milk-vetch	*Astragalus cimae var. cimae*	None	None	G2T2	S2.3	1B.2
Clark Mountain spurge	*Euphorbia exstipulata var. exstipulata*	None	None	G5T5?	S1.3	2.1
Cliff cinquefoil	*Potentilla rimicola*	None	None	G2G4	S1.3	2.3
Cliff spurge	*Euphorbia misera*	None	None	G5	S3.2	2.2
Clokey's cryptantha	*Cryptantha clokeyi*	None	None	G1	S1.1	1B.1
Coachella Valley milk-vetch	*Astragalus lentiginosus var. coachellae*	None	None	G5T2	S2.1	1B.2
Coulter's goldfields	*Lasthenia glabrata ssp. coulteri*	None	None	G4T3	S2.1	1B.1
Coves' cassia	*Senna covesii*	None	None	G5?	S2.2	2.2
Coyote gilia	*Aliciella triodon*	None	None	G5	S1.2	2.2
Creamy blazing star	*Mentzelia tridentata*	None	None	G2	S2.3	1B.3
Curved-spine beavertail	*Opuntia curvispina*	None	None	G3G4	S1.2	2.2
Cushenbury buckwheat	*Eriogonum ovalifolium var. vineum*	None	None	G5T1	S1.1	1B.1
Cushenbury milk-vetch	*Astragalus albens*	None	None	G1	S1.1	1B.1
Cushenbury oxytheca	*Acanthoscyphus parishii var. goodmaniana*	None	None	G4?T1	S1.1	1B.1

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Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Darlington's blazing star	*Mentzelia puberula*	None	None	G4	S2	2.2
Darwin rock-cress	*Arabis pulchra var. munciensis*	None	None	G5T4?	S1.3	2.3
Davidson's bush-mallow	*Malacothamnus davidsonii*	None	None	G1	S1.1	1B.2
Death Valley blue-eyed grass	*Sisyrinchium funereum*	Endangered	None	G2G3	S2.3	1B.3
Death Valley round-leaved phacelia	*Phacelia mustelina*	None	None	G2	S1.3	1B.3
Death Valley sandpaper-plant	*Petalonyx thurberi ssp. gilmanii*	None	None	G5T2	S2.3	1B.3
Deep Canyon snapdragon	*Antirrhinum cyathiferum*	None	None	G4?	S1.3	2.3
Delicate bluecup	*Githopsis tenella*	None	None	G2	S2.3	1B.3
Delicate muhly	*Muhlenbergia fragilis*	None	None	G5?	S1.3?	2.3
Desert ageratina	*Ageratina herbacea*	None	None	G5	S2.3	2.3
Desert bedstraw	*Galium proliferum*	None	None	G5	S2	2.2
Desert cymopterus	*Cymopterus deserticola*	None	None	G3	S3.2	1B.2
Desert germander	*Teucrium glandulosum*	None	None	G4	S1.3	2.3
Desert mountain thistle	*Cirsium arizonicum var. tenuisectum*	None	None	G5T2	S1.2	1B.2
Desert pincushion	*Coryphantha chlorantha*	None	None	G2G3	S1	2.1
Desert popcorn-flower	*Plagiobothrys salsus*	None	None	G2G3	S1.2?	2.2
Desert sand-parsley	*Ammoselinum giganteum*	None	None	G2G3	SH	2.3
Desert spike-moss	*Selaginella eremophila*	None	None	G4	S2.2?	2.2
Desert wing-fruit	*Selinocarpus nevadensis*	None	None	G5	S1.3	2.3
Drummond's false pennyroyal	*Hedeoma drummondii*	None	None	G5	S1.2	2.2
Dwarf abutilon	*Abutilon parvulum*	None	None	G5	S1.3	2.3
Dwarf germander	*Teucrium cubense ssp. depressum*	Endangered	None	G4G5T3T4	S2	2.2
Emory's crucifixion-thorn	*Castela emoryi*	None	None	G3	S2.2	2.3

Peer Draft

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Ewan's cinquefoil	*Potentilla glandulosa ssp. ewanii*	None	None	G5T1	S1	1B.3
False buffalo-grass	*Munroa squarrosa*	None	None	G5	S1S2	2.2
Few-flowered muhly	*Muhlenbergia pauciflora*	None	None	G5	S1.3?	2.3
Flat-seeded spurge	*Chamaesyce platysperma*	None	None	G3	S1.2?	1B.2
Forked buckwheat	*Eriogonum bifurcatum*	None	None	G2	S1.2	1B.2
Forked purple mat	*Nama dichotomum var. dichotomum*	None	None	G4T4?	S1.3?	2.3
Fort Tejon woolly sunflower	*Eriophyllum lanatum var. hallii*	None	None	G5T1	S1.1	1B.1
Foxtail thelypodium	*Thelypodium integrifolium ssp. complanatum*	None	None	G5T5	S2.2	2.2
Frog's-bit buttercup	*Ranunculus hydrocharoides*	None	None	G4G5	S1.1	2.1
Frosted mint	*Poliomintha incana*	Endangered	None	G5	SH	1A
Gander's cryptantha	*Cryptantha ganderi*	None	None	G1G2	S1.1	1B.1
Geyer's milk-vetch	*Astragalus geyeri var. geyeri*	None	None	G4T4	S2.2	2.2
Giant spanish-needle	*Palafoxia arida var. gigantea*	None	None	G5T3	S1.2	1B.3
Gilman's cymopterus	*Cymopterus gilmanii*	None	None	G3?	S2.2	2.3
Gilman's goldenbush	*Ericameria gilmanii*	None	None	G1	S1	1B.3
Glandular ditaxis	*Ditaxis claryana*	None	None	G4G5	S1S2	2.2
Golden violet	*Viola aurea*	None	None	G3G4	S2S3	2.2
Golden-carpet gilmania	*Gilmania luteola*	None	None	G1	S1.3	1B.3
Goodding's phacelia	*Phacelia pulchella var. gooddingii*	None	None	G5T2T3	S1.3?	2.3
Greata's aster	*Symphyotrichum greatae*	None	None	G2	S2.3	1B.3
Greene's rabbitbrush	*Chrysothamnus greenei*	None	None	G5	S3.2	2.3
Hairy erioneuron	*Erioneuron pilosum*	None	None	G5	S2S3	2.3

Peer Draft

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Hairy stickleaf	*Mentzelia hirsutissima*	None	None	G3?	S2S3	2.3
Hairy-podded fine-leaf hymenopappus	*Hymenopappus filifolius var. eriopodus*	None	None	G5T3	S1.3	2.3
Hall's daisy	*Erigeron aequifolius*	None	None	G2	S2.3	1B.3
Hall's meadow hawksbeard	*Crepis runcinata ssp. hallii*	None	None	G5T3?	S2?	2.1
Hall's monardella	*Monardella macrantha ssp. hallii*	None	None	G5T3	S3.3	1B.3
Harwood's eriastrum	*Eriastrum harwoodii*	Endangered	None	G2	S2	1B.2
Harwood's milk-vetch	*Astragalus insularis var. harwoodii*	None	None	G5T3	S2.2?	2.2
Hidden Lake bluecurls	*Trichostema austromontanum ssp. compactum*	None	None	G3G4T1	S1.1	1B.1
Hillman's silverscale	*Atriplex argentea var. hillmanii*	None	None	G5T3?	S2.2	2.2
Hillside wheat grass	*Leymus salinus ssp. mojavensis*	None	None	G5T3?	S1.3	2.3
Hoffmann's buckwheat	*Eriogonum hoffmannii var. hoffmannii*	None	None	G3T2	S2.3	1B.3
Horn's milk-vetch	*Astragalus hornii var. hornii*	None	None	G4G5T2T3	S2S3.1	1B.1
Hot springs fimbristylis	*Fimbristylis thermalis*	None	None	G4	S2.2	2.2
Howe's hedgehog cactus	*Echinocereus engelmannii var. howei*	None	None	G5T1	S1.1	1B.1
Inland rush	*Juncus interior*	None	None	G4	S1	2.2
Inyo blazing star	*Mentzelia inyoensis*	None	None	G2	S2.3	1B.3
Inyo County star-tulip	*Calochortus excavatus*	None	None	G3	S3.1	1B.1
Inyo phacelia	*Phacelia inyoensis*	None	None	G3	S3.2	1B.2

Peer Draft

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Ivory-spined agave	*Agave utahensis var. eborispina*	None	None	G4T3Q	S1.3	1B.3
Jackass-clover	*Wislizenia refracta ssp. refracta*	None	None	G5T5?	S1.2?	2.2
Jaeger's ivesia	*Ivesia jaegeri*	None	None	G2G3	S1.3	1B.3
Jaeger's phacelia	*Phacelia perityloides var. jaegeri*	None	None	G4T2	S1.3	1B.3
Johnson's bee-hive cactus	*Sclerocactus johnsonii*	None	None	G3G4	S2.2	2.2
Johnston's buckwheat	*Eriogonum microthecum var. johnstonii*	None	None	G5T2	S2	1B.3
Johnston's rock-cress	*Arabis johnstonii*	None	None	G1	S1.2	1B.2
Jointed buckwheat	*Eriogonum intrafractum*	None	None	G2	S2.3	1B.3
Juniper sulphur-flowered buckwheat	*Eriogonum umbellatum var. juniporinum*	None	None	G5T3?	S1S2	2.3
Kelso Creek monkeyflower	*Mimulus shevockii*	None	None	G2	S2	1B.2
Kern buckwheat	*Eriogonum kennedyi var. pinicola*	Threatened	None	G4T1	S1.1	1B.1
King's eyelash grass	*Blepharidachne kingii*	Endangered	None	G4	S1.3	2.3
Kingston Mountains bedstraw	*Galium hilendiae ssp. kingstonense*	None	None	G4T2	S1.3	1B.3
Kingston Mountains ivesia	*Ivesia patellifera*	None	None	G1	S1.3	1B.3
Knotted rush	*Juncus nodosus*	None	None	G5	S2.3	2.3
Kofa barberry	*Berberis harrisoniana*	None	None	G1G2	S1.2	1B.2
Lancaster milk-vetch	*Astragalus preussii var. laxiflorus*	Threatened	None	G4T2	S1	1B.1
Lane Mountain milk-vetch	*Astragalus jaegerianus*	None	None	G1	S1.1	1B.1
Las Animas colubrina	*Colubrina californica*	None	None	G4	S2S3.3	2.3

Peer Draft

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Latimer's woodland-gilia	*Saltugilia latimeri*	None	None	G2	S2.2	1B.2
Lemon lily	*Lilium parryi*	None	None	G3	S2.1	1B.2
Limestone beardtongue	*Penstemon calcareus*	None	None	G2	S2.3	1B.3
Limestone daisy	*Erigeron uncialis var. uncialis*	Threatened	None	G3G4T2	S2.2	1B.2
Little purple monkeyflower	*Mimulus purpureus*	None	None	G2	S2.2	1B.2
Little San Bernardino Mtns. linanthus	*Linanthus maculatus*	None	None	G1	S1.2	1B.2
Little-leaf elephant tree	*Bursera microphylla*	None	None	G4	S2.3	2.3
Lobed ground-cherry	*Physalis lobata*	None	None	G5	S1.3?	2.3
Long-stem evening-primrose	*Oenothera longissima*	None	None	G4	S1.2	2.2
Los Angeles sunflower	*Helianthus nuttallii ssp. parishii*	None	None	G5TH	SH	1A
Madera leptosiphon	*Leptosiphon serrulatus*	None	None	G1?	S1?	1B.2
Male fern	*Dryopteris filix-mas*	None	None	G5	S1.3	2.3
Many-flowered schkuhria	*Schkuhria multiflora var. multiflora*	None	None	G5T5	S1.3	2.3
Mecca-aster	*Xylorhiza cognata*	None	None	G2	S2.2	1B.2
Mesquite neststraw	*Stylocline sonorensis*	None	None	G3G5	SX	1A
Mingan moonwort	*Botrychium minganense*	None	None	G4	S1.2	2.2
Mojave Desert plum	*Prunus eremophila*	None	None	G1	S1.2	1B.2
Mojave milkweed	*Asclepias nyctaginifolia*	None	None	G4G5	S1	2.1
Mojave monkeyflower	*Mimulus mohavensis*	None	None	G2	S2.2	1B.2
Mojave tarplant	*Deinandra mohavensis*	None	Endangered	G2	S2.3	1B.3
Mormon needle grass	*Achnatherum aridum*	Endangered	None	G5	S2?	2.3
Mountain Springs bush lupine	*Lupinus excubitus var. medius*	None	None	G4T2T3	S2.3	1B.3
Mt. Gleason paintbrush	*Castilleja gleasonii*	Threatened	Rare	G2Q	S2.2	1B.2

Peer Draft

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Mud nama	*Nama stenocarpum*	None	None	G4G5	S1S2	2.2
Muir's tarplant	*Carlquistia muirii*	None	None	G2	S2.3	1B.3
Munz's cholla	*Opuntia munzii*	None	None	G3	S1.2	1B.3
Narrow-leaved cottonwood	*Populus angustifolia*	None	None	G5	S2S3	2.2
Narrow-leaved psorothamnus	*Psorothamnus fremontii var. attenuatus*	None	None	G5T3?	S2.3	2.3
Narrow-leaved yerba santa	*Eriodictyon angustifolium*	None	None	G5	S2.3	2.3
Nevada onion	*Allium nevadense*	None	None	G4	S1.3	2.3
Nevada oryctes	*Oryctes nevadensis*	None	None	G2G3	S1.1	2.1
Nevin's barberry	*Berberis nevinii*	None	Endangered	G2	S2.2	1B.1
New Mexico locust	*Robinia neomexicana*	None	None	G4	S1.3	2.3
Nine Mile Canyon phacelia	*Phacelia novenmillensis*	None	None	G2	S2.2	1B.2
Nine-awned pappus grass	*Enneapogon desvauxii*	None	None	G5	S2	2.2
Notch-beaked milkwort	*Polygala heterorhyncha*	None	None	G3	S1.3	2.3
Orcutt's linanthus	*Linanthus orcuttii*	None	None	G4	S2.3	1B.3
Orcutt's woody-aster	*Xylorhiza orcuttii*	None	None	G2G3	S2.2	1B.2
Orocopia sage	*Salvia greatae*	None	None	G2	S2.2	1B.3
Owens Peak lomatium	*Lomatium shevockii*	None	None	G1	S1.3	1B.3
Owens Valley checkerbloom	*Sidalcea covillei*	None	Endangered	G3	S3.1	1B.1
Pale-yellow layia	*Layia heterotricha*	None	None	G2G3	S2S3.1	1B.1
Palmer's mariposa-lily	*Calochortus palmeri var. palmeri*	None	None	G2T2	S2.1	1B.2
Panamint daisy	*Enceliopsis covillei*	None	None	G3	S3.3	1B.2
Parish's alkali grass	*Puccinellia parishii*	None	None	G2G3	S1	1B.1
Parish's alumroot	*Heuchera parishii*	None	None	G2	S2.3	1B.3
Parish's brittlescale	*Atriplex parishii*	None	None	G1G2	S1.1	1B.1

Peer Draft

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Parish's club-cholla	*Grusonia parishii*	Threatened	None	G3G4	S2	2.2
Parish's daisy	*Erigeron parishii*	None	None	G2	S2.1	1B.1
Parish's desert-thorn	*Lycium parishii*	None	None	G3?	S2S3	2.3
Parish's phacelia	*Phacelia parishii*	None	None	G2G3	S1.1	1B.1
Parish's popcorn-flower	*Plagiobothrys parishii*	None	None	G1	S1.1	1B.1
Parish's rock-cress	*Arabis parishii*	None	None	G2	S2.1	1B.2
Parish's yampah	*Perideridia parishii ssp. parishii*	None	None	G4T3T4	S2.2?	2.2
Parry's spineflower	*Chorizanthe parryi var. parryi*	Candidate	None	G3T2	S2	1B.1
Parry's spurge	*Chamaesyce parryi*	None	None	G5	S1.3	2.3
Peirson's lupine	*Lupinus peirsonii*	None	None	G2	S2.3	1B.3
Peirson's milk-vetch	*Astragalus magdalenae var. peirsonii*	None	Endangered	G3G4T2	S2.2	1B.2
Peirson's pincushion	*Chaenactis carphoclinia var. peirsonii*	None	None	G5T1	S1.3	1B.3
Pink fairy-duster	*Calliandra eriophylla*	None	None	G5	S2.3	2.3
Pinyon rock-cress	*Arabis dispar*	None	None	G3	S2.3	2.3
Piute cypress	*Callitropsis nevadensis*	None	None	G2	S2.2	1B.2
Piute Mountains jewel-flower	*Streptanthus cordatus var. piutensis*	None	None	G5T1	S1.2	1B.2
Piute Mountains navarretia	*Navarretia setiloba*	None	None	G1	S1.1	1B.1
Plains bee balm	*Monarda pectinata*	None	None	G5	S1.3	2.3
Plains flax	*Linum puberulum*	None	None	G5	S1S2.3	2.3
Plains stoneseed	*Lithospermum incisum*	None	None	G5	S1.3	2.3
Playa milk-vetch	*Astragalus allochrous var. playanus*	Endangered	None	G4T3?	S1.2	2.2
Plummer's mariposa-lily	*Calochortus plummerae*	None	None	G3	S3.2	1B.2
Plummer's woodsia	*Woodsia plummerae*	None	None	G5	S1.3?	2.3

Peer Draft

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Polished blazing star	*Mentzelia polita*	None	None	G2	S1.2	1B.2
Preuss' milk-vetch	*Astragalus preussii var. preussii*	None	None	G4T4	S1.2	2.3
Providence Mountains lotus	*Lotus argyraeus var. notitius*	None	None	G4?T1	S1.3	1B.3
Pungent glossopetalon	*Glossopetalon pungens*	None	None	G2G3	S1.3	1B.2
Purple stemodia	*Stemodia durantifolia*	None	None	G5	S2.1?	2.1
Purple-nerve cymopterus	*Cymopterus multinervatus*	None	None	G5	S2	2.2
Pygmy lotus	*Lotus haydonii*	None	None	G3	S2.3?	1B.3
Pygmy pussypaws	*Calyptridium pygmaeum*	None	None	G2	S2	1B.2
Recurved larkspur	*Delphinium recurvatum*	None	None	G2	S2.2	1B.2
Red four o'clock	*Mirabilis coccinea*	None	None	G5	S2.3	2.3
Red Rock poppy	*Eschscholzia minutiflora ssp. twisselmannii*	None	None	G5T2	S2.2	1B.2
Red Rock tarplant	*Deinandra arida*	None	Rare	G1	S1.2	1B.2
Ripley's aliciella	*Aliciella ripleyi*	None	None	G3	S1.3	2.3
Robison's monardella	*Monardella robisonii*	None	None	G2	S2.3	1B.3
Robust Hoffmann's buckwheat	*Eriogonum hoffmannii var. robustius*	None	None	G3T2	S2.3	1B.3
Rock Creek broomrape	*Orobanche valida ssp. valida*	None	None	G3T2	S2	1B.2
Rosy two-toned beardtongue	*Penstemon bicolor ssp. roseus*	None	None	G3T3Q	S1	1B.1
Rough menodora	*Menodora scabra*	None	None	G5	S2.3	2.3
Round-leaved filaree	*California macrophylla*	None	None	G3	S3.1	1B.1
Rusby's desert-mallow	*Sphaeralcea rusbyi var. eremicola*	None	None	G4T2	S2	1B.2
Sagebrush loeflingia	*Loeflingia squarrosa var. artemisiarum*	None	None	G5T2T3	S2.2	2.2
Saguaro	*Carnegiea gigantea*	None	None	G5	S1.2	2.2

Peer Draft

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Salt Spring checkerbloom	*Sidalcea neomexicana*	None	None	G4?	S2S3	2.2
San Antonio milk-vetch	*Astragalus lentiginosus var. antonius*	Endangered	None	G5T1	S1?	1B.3
San Bernardino aster	*Symphyotrichum defoliatum*	None	None	G3	S3.2	1B.2
San Bernardino blue grass	*Poa atropurpurea*	None	None	G2	S2.2	1B.2
San Bernardino Mountains bladderpod	*Lesquerella kingii ssp. bernardina*	None	None	G5T1	S1	1B.1
San Bernardino Mountains dudleya	*Dudleya abramsii ssp. affinis*	None	None	G3T2	S2.2	1B.2
San Bernardino Mountains monkeyflower	*Mimulus exiguus*	None	None	G2	S2.2	1B.2
San Bernardino Mountains owl's-clover	*Castilleja lasiorhyncha*	None	None	G2	S2.2	1B.2
San Bernardino ragwort	*Packera bernardina*	None	None	G2	S2.2	1B.2
San Felipe monardella	*Monardella nana ssp. leptosiphon*	None	None	G4G5T2	S2.2	1B.2
San Fernando Valley spineflower	*Chorizanthe parryi var. fernandina*	None	Endangered	G2T1	S1.1	1B.1
San Gabriel linanthus	*Linanthus concinnus*	None	None	G2?	S2?	1B.2
San Jacinto linanthus	*Linanthus jaegeri*	None	None	G2	S2.2	1B.2
San Jacinto Mountains bedstraw	*Galium angustifolium ssp. jacinticum*	None	None	G5T1T2	S1S2	1B.3
Sand evening-primrose	*Camissonia arenaria*	None	None	G4?	S2	2.2
Sand food	*Pholisma sonorae*	None	None	G2	S1.2	1B.2
Sanicle cymopterus	*Cymopterus ripleyi var. saniculoides*	None	None	G3G4T3Q	S1.2	1B.2
Santa Ana River woollystar	*Eriastrum densifolium ssp. sanctorum*	None	Endangered	G4T1	S1	1B.1

Peer Draft

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Santa Rosa Mountains leptosiphon	*Leptosiphon floribundus ssp. hallii*	None	None	G4T1	S1	1B.3
Scalloped moonwort	*Botrychium crenulatum*	None	None	G3	S2.2	2.2
Scaly cloak fern	*Astrolepis cochisensis ssp. cochisensis*	Endangered	None	G5?T4	S2.3	2.3
Scrub lotus	*Lotus argyraeus var. multicaulis*	None	None	G4?T1	S1.3	1B.3
Shaggy-haired alumroot	*Heuchera hirsutissima*	None	None	G2	S2.3	1B.3
Shevock's bristle moss	*Orthotrichum shevockii*	None	None	G2	S2	1B.3
Shockley's rock-cress	*Arabis shockleyi*	None	None	G3	S2.2	2.2
Short-joint beavertail	*Opuntia basilaris var. brachyclada*	None	None	G5T3	S3	1B.2
Short-sepaled lewisia	*Lewisia brachycalyx*	Endangered	None	G4G5	S3.2	2.2
Silver-haired ivesia	*Ivesia argyrocoma*	None	None	G2	S2.2	1B.2
Singlewhorl burrobrush	*Ambrosia monogyra*	None	None	G5	S2.2	2.2
Sky-blue phacelia	*Phacelia coerulea*	None	None	G5	S1.3	2.3
Slender cottonheads	*Nemacaulis denudata var. gracilis*	None	None	G3G4T3?	S2S3	2.2
Slender mariposa-lily	*Calochortus clavatus var. gracilis*	None	None	G4T2	S2	1B.2
Slender-horned spineflower	*Dodecahema leptoceras*	None	Endangered	G1	S1	1B.1
Slender-petaled thelypodium	*Thelypodium stenopetalum*	None	Endangered	G1	S1.1	1B.1
Slender-spined all-thorn	*Koeberlinia spinosa ssp. tenuispina*	None	None	G4T4	S2.2	2.2
Slender-stem bean	*Phaseolus filiformis*	None	None	G5	S1	2.1
Small-flowered androstephium	*Androstephium breviflorum*	None	None	G5	S1.2	2.2

Peer Draft

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Small-flowered bird's-beak	*Cordylanthus parviflorus*	None	None	G4G5	S1S2	2.3
Small-flowered rice grass	*Piptatherum micranthum*	None	None	G5	S2S3	2.3
Small-flowered sand-verbena	*Tripterocalyx micranthus*	Threatened	None	G5	S1.3	2.3
Smooth tarplant	*Centromadia pungens ssp. laevis*	None	None	G3G4T2	S2.1	1B.1
Sodaville milk-vetch	*Astragalus lentiginosus var. sesquimetralis*	Endangered	Endangered	G5T1	S1.1	1B.1
Sonoran maiden fern	*Thelypteris puberula var. sonorensis*	Endangered	None	G5T3	S2.2?	2.2
Southern alpine buckwheat	*Eriogonum kennedyi var. alpigenum*	None	None	G4T2	S2.3	1B.3
Southern California rock draba	*Draba corrugata var. saxosa*	Endangered	None	G2T2	S2.3	1B.3
southern jewel-flower	*Streptanthus campestris*	None	None	G2	S2.3	1B.3
Southern mountain buckwheat	*Eriogonum kennedyi var. austromontanum*	None	None	G4T2	S2.2	1B.2
Southern mountains skullcap	*Scutellaria bolanderi ssp. austromontana*	None	None	G4T2	S2.2?	1B.2
Southwestern false cloak-fern	*Argyrochosma limitanea var. limitanea*	Threatened	None	G4G5T3T4	S2.3	2.3
Spanish Needle onion	*Allium shevockii*	None	None	G1	S1.3	1B.3
Spear-leaf matelea	*Matelea parvifolia*	None	None	G5?	S2.2	2.3
Spine-noded milk vetch	*Peteria thompsoniae*	None	None	G4	S1.3?	2.3
Spiny cliff-brake	*Pellaea truncata*	None	None	G5	S2	2.3
Spjut's bristle moss	*Orthotrichum spjutii*	None	None	G1	S1	1B.3
Stephens' beardtongue	*Penstemon stephensii*	None	None	G2	S2.3	1B.3
Tahquitz ivesia	*Ivesia callida*	None	Rare	G1	S1.3	1B.3
Tecopa bird's-beak	*Cordylanthus tecopensis*	None	None	G2	S1.2	1B.2

Peer Draft

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Tehachapi buckwheat	*Eriogonum callistum*	None	None	G1	S1	1B.1
Tehachapi monardella	*Monardella linoides ssp. oblonga*	None	None	G5T2	S2.2	1B.3
Thompson's beardtongue	*Penstemon thompsoniae*	None	None	G4	S1.3	2.3
Thorne's buckwheat	*Eriogonum thornei*	Endangered	Endangered	G1	S1.1	1B.2
Thorny milkwort	*Polygala acanthoclada*	None	None	G4	S2.3	2.3
Three-awned grama	*Bouteloua trifida*	None	None	G4G5	S2?	2.3
Tidestrom's milk-vetch	*Astragalus tidestromii*	None	None	G4G5	S2	2.2
Torrey's blazing star	*Mentzelia torreyi*	None	None	G4	S2.2	2.2
Tough muhly	*Muhlenbergia arsenei*	None	None	G5	S1S2	2.3
Tracy's eriastrum	*Eriastrum tracyi*	None	Rare	G1Q	S1.1	1B.2
Triple-ribbed milk-vetch	*Astragalus tricarinatus*	None	None	G1	S1.2	1B.2
Utah beardtongue	*Penstemon utahensis*	None	None	G4	S2.3	2.3
Utah daisy	*Erigeron utahensis*	None	None	G4	S1.3	2.3
Utah glasswort	*Sarcocornia utahensis*	None	None	G4?	S1.2	2.2
Utah monkeyflower	*Mimulus glabratus ssp. utahensis*	None	None	G5T5?	S1.1	2.1
Violet twining snapdragon	*Maurandya antirrhiniflora ssp. antirrhiniflora*	None	None	G4G5T3?	S1.3	2.3
Viviparous foxtail cactus	*Coryphantha vivipara var. rosea*	None	None	G5T3	S2.2	2.2
Wand-like fleabane daisy	*Erigeron oxyphyllus*	None	None	G2G4	S1.3	2.3
White bear poppy	*Arctomecon merriamii*	None	None	G3	S2.2	2.2
White-bracted spineflower	*Chorizanthe xanti var. leucotheca*	None	None	G4T2	S2.2	1B.2
White-margined beardtongue	*Penstemon albomarginatus*	None	None	G2	S1	1B.1
Wiggins' croton	*Croton wigginsii*	None	Rare	G2G3	S1.2	2.2
Wing-seed blazing star	*Mentzelia pterosperma*	None	None	G4	S1.2	2.2

Peer Draft

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Wolftail	*Muhlenbergia alopecuroides*	None	None	G5	S1?	2.2
Woolly mountain-parsley	*Oreonana vestita*	None	None	G3	S3.3	1B.3
Wooton's lace fern	*Cheilanthes wootonii*	None	None	G5	S1.3	2.3
Wright's bedstraw	*Galium wrightii*	None	None	G3G4	S1.2	2.3
Yellow ivesia	*Ivesia arizonica var. arizonica*	None	None	G3G4T3	S1	2.3
Yucaipa onion	*Allium marvinii*	None	None	G1	S1.1	1B.1

[1] Regulatory Status

Federal = federally listed as endangered or threatened or candidate for listing

State = state-listed as endangered, threatened, or rare

G-Rank = California Natural Diversity Database (CNDDB) Element, Global Ranking:

G1 = Less than 6 viable element occurrences OR less than 1,000 individuals OR less than 2,000 acres

G2 = 6-20 element occurrences OR 1,000-3,000 individuals OR 2,000-10,000 acres

G3 = 21-80 element occurrences OR 3,000-10,000 individuals OR 10,000-50,000 acres

G4 = Apparently secure, but some threat or somewhat narrow habitat

G5 = Population or stand demonstrably secure to ineradicable due to being commonly found in the world

Note: Subspecies receive a T-rank attached to the G-rank; the G-rank then refers to the entire species, whereas the T-rank refers to the subspecies or variety.

S-Rank = CNDDB Element, State Ranking:

S1= Less than 6 occurrences OR less than 1,000 individuals OR less than 2,000 acres

S1.1 = very threatened

S1.2 = threatened

S1.3 = no current threats known

S2 = 6-20 element occurrences OR 1,000-3,000 individuals OR 2,000-10,000 acres

S2.1 = very threatened

S2.2 = threatened

S2.3 = no current threats known

S3 = 21-80 element occurrences OR 3,000-10,000 individuals OR 10,000-50,000 acres

S3.1 = very threatened

Peer Draft

S3.2 = threatened

S3.3 = no current threats known

S4 = Apparently secure, but some threat or somewhat narrow habitat (no threat rank)

S5 = Population or stand demonstrably secure to ineradicable due to being commonly found in California (no threat rank)

CNPS:

1B = CNPS List 1B – Rare, threatened, or endangered in California and elsewhere

0.1: Seriously endangered in California

0.2: Fairly endangered in California

0.3: Not very endangered in California

2 = CNPS List 2 – Rare threatened, or endangered in California, but more common elsewhere

0.1: Seriously endangered in California

0.2: Fairly endangered in California

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Appendix E

CNPS List 1B & 2 Species most likely to be affected by renewable energy projects

This list of high priority "at risk" species includes rare plants with occurrences documented by the California Natural Diversity Data Base that fell within a proposed project footprint and/or within a BLM Solar Energy Study Area (SESA) as of June, 2010. GIS layers included in the analysis:

- BLM renewable energy project layers
- DFG renewable energy project layers
- RETI renewable energy project layers
- RETI transmission line layers
- RETI substation layer
- BLM SESA layer
- REAT RESA layer

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Abert's sanvitalia	*Sanvitalia abertii*	None	None	G5	S1S2	2.2
Abrams' spurge	*Chamaesyce abramsiana*	None	None	G4	S1.2	2.2
Algodones Dunes sunflower	*Helianthus niveus ssp. tephrodes*	None	Endangered	G4T2	S1.2	1B.2
Alkali mariposa-lily	*Calochortus striatus*	None	None	G2	S2	1B.2
Angel trumpets	*Acleisanthes longiflora*	None	None	G5	S1.3	2.3
Annual rock-nettle	*Eucnide rupestris*	None	None	G3	S1	2.2
Arizona spurge	*Chamaesyce arizonica*	None	None	G5	S1.3	2.3

Paper Draft

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Ash-gray paintbrush	*Castilleja cinerea*	None	None	G2	S2.2	1B.2
Aven Nelson's phacelia	*Phacelia anelsonii*	None	None	G2G3	S2.3?	2.3
Baja navarretia	*Navarretia peninsularis*	None	None	G3?	S2.2	1B.2
Bald daisy	*Erigeron calvus*	None	None	G1Q	S1.1	1B.1
Baldwin Lake linanthus	*Linanthus killipii*	None	None	G2	S2.1	1B.2
Barneby's phacelia	*Phacelia barnebyana*	None	None	G3?	S2.3	2.3
Barstow woolly sunflower	*Eriophyllum mohavense*	None	None	G2	S2.2	1B.2
Bear Lake buckwheat	*Eriogonum microthecum var. lacus-ursi*	None	None	G5T1	S1.1	1B.1
Bear Valley pyrrocoma	*Pyrrocoma uniflora var. gossypina*	None	None	G5T2	S2.2	1B.2
Big Bear Valley milk-vetch	*Astragalus lentiginosus var. sierrae*	None	None	G5T1	S1?	1B.2
Big Bear Valley phlox	*Phlox dolichantha*	None	None	G2	S2.2	1B.2
Big Bear Valley sandwort	*Arenaria ursina*	None	None	G2	S2.1	1B.2
Big Bear Valley woollypod	*Astragalus leucolobus*	None	None	G2	S2.2	1B.2
Bird-foot checkerbloom	*Sidalcea pedata*	None	Endangered	G1	S1.1	1B.1
Bitter hymenoxys	*Hymenoxys odorata*	None	None	G5	S2	2
Black bog-rush	*Schoenus nigricans*	None	None	G4	S2.2	2.2
Booth's evening-primrose	*Camissonia boothii ssp. boothii*	None	None	G5T4	S2.3	2.3
Booth's hairy evening-primrose	*Camissonia boothii ssp. intermedia*	None	None	G5T3T4	S2.3	2.3
Brown fox sedge	*Carex vulpinoidea*	None	None	G5	S2.2	2.2
Brown turbans	*Malperia tenuis*	None	None	G4?	S1.3	2.3
Calico monkeyflower	*Mimulus pictus*	None	None	G2	S2.2	1B.2
California dandelion	*Taraxacum californicum*	None	None	G2	S2.1	1B.1
California satintail	*Imperata brevifolia*	None	None	G2	S2.1	2.1
Chambers' physaria	*Physaria chambersii*	None	None	G4	S2.3	2.3

Peer Draft

Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Chaparral sand-verbena	*Abronia villosa var. aurita*	Endangered	None	G5T3T4	S2.1	1B.1
Charlotte's phacelia	*Phacelia nashiana*	None	None	G3	S3.2	1B.2
Clark Mountain spurge	*Euphorbia exstipulata var. exstipulata*	None	None	G5T5?	S1.3	2.1
Cliff spurge	*Euphorbia misera*	None	None	G5	S3.2	2.2
Coachella Valley milk-vetch	*Astragalus lentiginosus var. coachellae*	None	None	G5T2	S2.1	1B.2
Coulter's goldfields	*Lasthenia glabrata ssp. coulteri*	None	None	G4T3	S2.1	1B.1
Coves' cassia	*Senna covesii*	None	None	G5?	S2.2	2.2
Creamy blazing star	*Mentzelia tridentata*	None	None	G2	S2.3	1B.3
Cushenbury buckwheat	*Eriogonum ovalifolium var. vineum*	None	None	G5T1	S1.1	1B.1
Cushenbury milk-vetch	*Astragalus albens*	None	None	G1	S1.1	1B.1
Cushenbury oxytheca	*Acanthoscyphus parishii var. goodmaniana*	None	None	G4?T1	S1.1	1B.1
Darlington's blazing star	*Mentzelia puberula*	None	None	G4	S2	2.2
Desert cymopterus	*Cymopterus deserticola*	None	None	G3	S3.2	1B.2
Desert pincushion	*Coryphantha chlorantha*	None	None	G2G3	S1	2.1
Desert sand-parsley	*Ammoselinum giganteum*	None	None	G2G3	SH	2.3
Desert spike-moss	*Selaginella eremophila*	None	None	G4	S2.2?	2.2
Dwarf germander	*Teucrium cubense ssp. depressum*	Endangered	None	G4G5T3T4	S2	2.2
Emory's crucifixion-thorn	*Castela emoryi*	None	None	G3	S2.2	2.3
Ewan's cinquefoil	*Potentilla glandulosa ssp. ewanii*	None	None	G5T1	S1	1B.3
Flat-seeded spurge	*Chamaesyce platysperma*	None	None	G3	S1.2?	1B.2
Foxtail thelypodium	*Thelypodium integrifolium ssp. complanatum*	None	None	G5T5	S2.2	2.2
Frosted mint	*Poliomintha incana*	Endangered	None	G5	SH	1A

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Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Geyer's milk-vetch	*Astragalus geyeri var. geyeri*	None	None	G4T4	S2.2	2.2
Giant Spanish-needle	*Palafoxia arida var. gigantea*	None	None	G5T3	S1.2	1B.3
Gilman's cymopterus	*Cymopterus gilmanii*	None	None	G3?	S2.2	2.3
Glandular ditaxis	*Ditaxis claryana*	None	None	G4G5	S1S2	2.2
Golden violet	*Viola aurea*	None	None	G3G4	S2S3	2.2
Hairy stickleaf	*Mentzelia hirsutissima*	None	None	G3?	S2S3	2.3
Harwood's eriastrum	*Eriastrum harwoodii*	Endangered	None	G2	S2	1B.2
Harwood's milk-vetch	*Astragalus insularis var. harwoodii*	None	None	G5T3	S2.2?	2.2
Hillman's silverscale	*Atriplex argentea var. hillmanii*	None	None	G5T3?	S2.2	2.2
Horn's milk-vetch	*Astragalus hornii var. hornii*	None	None	G4G5T2T3	S2S3.1	1B.1
Howe's hedgehog cactus	*Echinocereus engelmannii var. howei*	None	None	G5T1	S1.1	1B.1
Inyo County star-tulip	*Calochortus excavatus*	None	None	G3	S3.1	1B.1
Jackass-clover	*Wislizenia refracta ssp. refracta*	None	None	G5T5?	S1.2?	2.2
Kelso Creek monkeyflower	*Mimulus shevockii*	None	None	G2	S2	1B.2
Kern buckwheat	*Eriogonum kennedyi var. pinicola*	Threatened	None	G4T1	S1.1	1B.1
Lancaster milk-vetch	*Astragalus preussii var. laxiflorus*	Threatened	None	G4T2	S1	1B.1
Lane Mountain milk-vetch	*Astragalus jaegerianus*	None	None	G1	S1.1	1B.1
Las Animas colubrina	*Colubrina californica*	None	None	G4	S2S3.3	2.3
Latimer's woodland-gilia	*Saltugilia latimeri*	None	None	G2	S2.2	1B.2

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Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Lemon lily	*Lilium parryi*	None	None	G3	S2.1	1B.2
Little purple monkeyflower	*Mimulus purpureus*	None	None	G2	S2.2	1B.2
Little San Bernardino Mtns. linanthus	*Linanthus maculatus*	None	None	G1	S1.2	1B.2
Madera leptosiphon	*Leptosiphon serrulatus*	None	None	G1?	S1?	1B.2
Male fern	*Dryopteris filix-mas*	None	None	G5	S1.3	2.3
Mecca-aster	*Xylorhiza cognata*	None	None	G2	S2.2	1B.2
Mesquite neststraw	*Stylocline sonorensis*	None	None	G3G5	SX	1A
Mojave milkweed	*Asclepias nyctaginifolia*	None	None	G4G5	S1	2.1
Mojave monkeyflower	*Mimulus mohavensis*	None	None	G2	S2.2	1B.2
Mojave tarplant	*Deinandra mohavensis*	None	Endangered	G2	S2.3	1B.3
Mormon needle grass	*Achnatherum aridum*	Endangered	None	G5	S2?	2.3
Munz's cholla	*Opuntia munzii*	None	None	G3	S1.2	1B.3
Nevada onion	*Allium nevadense*	None	None	G4	S1.3	2.3
Nevada oryctes	*Oryctes nevadensis*	None	None	G2G3	S1.1	2.1
Nevin's barberry	*Berberis nevinii*	None	Endangered	G2	S2.2	1B.1
Nine-awned pappus grass	*Enneapogon desvauxii*	None	None	G5	S2	2.2
Orcutt's woody-aster	*Xylorhiza orcuttii*	None	None	G2G3	S2.2	1B.2
Orocopia sage	*Salvia greatae*	None	None	G2	S2.2	1B.3
Owens Valley checkerbloom	*Sidalcea covillei*	None	Endangered	G3	S3.1	1B.1
Pale-yellow layia	*Layia heterotricha*	None	None	G2G3	S2S3.1	1B.1
Palmer's mariposa-lily	*Calochortus palmeri var. palmeri*	None	None	G2T2	S2.1	1B.2
Parish's alumroot	*Heuchera parishii*	None	None	G2	S2.3	1B.3
Parish's brittlescale	*Atriplex parishii*	None	None	G1G2	S1.1	1B.1
Parish's checkerbloom	*Sidalcea hickmanii ssp. parishii*	None	Rare	G3T1	S1.2	1B.2
Parish's club-cholla	*Grusonia parishii*	Threatened	None	G3G4	S2	2.2

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Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Parish's daisy	*Erigeron parishii*	None	None	G2	S2.1	1B.1
Parish's desert-thorn	*Lycium parishii*	None	None	G3?	S2S3	2.3
Parish's phacelia	*Phacelia parishii*	None	None	G2G3	S1.1	1B.1
Parish's popcorn-flower	*Plagiobothrys parishii*	None	None	G1	S1.1	1B.1
Parish's rock-cress	*Arabis parishii*	None	None	G2	S2.1	1B.2
Parish's yampah	*Perideridia parishii ssp. parishii*	None	None	G4T3T4	S2.2?	2.2
Parry's spineflower	*Chorizanthe parryi var. parryi*	Candidate	None	G3T2	S2	1B.1
Peirson's milk-vetch	*Astragalus magdalenae var. peirsonii*	None	Endangered	G3G4T2	S2.2	1B.2
Peirson's pincushion	*Chaenactis carphoclinia var. peirsonii*	None	None	G5T1	S1.3	1B.3
Pink fairy-duster	*Calliandra eriophylla*	None	None	G5	S2.3	2.3
Pinyon rock-cress	*Arabis dispar*	None	None	G3	S2.3	2.3
Piute cypress	*Callitropsis nevadensis*	None	None	G2	S2.2	1B.2
Piute Mountains jewel-flower	*Streptanthus cordatus var. piutensis*	None	None	G5T1	S1.2	1B.2
Piute Mountains navarretia	*Navarretia setiloba*	None	None	G1	S1.1	1B.1
Plains bee balm	*Monarda pectinata*	None	None	G5	S1.3	2.3
Plains flax	*Linum puberulum*	None	None	G5	S1S2.3	2.3
Plummer's mariposa-lily	*Calochortus plummerae*	None	None	G3	S3.2	1B.2
Purple stemodia	*Stemodia durantifolia*	None	None	G5	S2.1?	2.1
Purple-nerve cymopterus	*Cymopterus multinervatus*	None	None	G5	S2	2.2
Pygmy pussypaws	*Calyptridium pygmaeum*	None	None	G2	S2	1B.2
Recurved larkspur	*Delphinium recurvatum*	None	None	G2	S2.2	1B.2
Red four o'clock	*Mirabilis coccinea*	None	None	G5	S2.3	2.3
Red Rock poppy	*Eschscholzia minutiflora ssp. twisselmannii*	None	None	G5T2	S2.2	1B.2

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Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Red Rock tarplant	*Deinandra arida*	None	Rare	G1	S1.2	1B.2
Ripley's aliciella	*Aliciella ripleyi*	None	None	G3	S1.3	2.3
Rosy two-toned beardtongue	*Penstemon bicolor ssp. roseus*	None	None	G3T3Q	S1	1B.1
Round-leaved filaree	*California macrophylla*	None	None	G3	S3.1	1B.1
Rusby's desert-mallow	*Sphaeralcea rusbyi var. eremicola*	None	None	G4T2	S2	1B.2
Sagebrush loeflingia	*Loeflingia squarrosa var. artemisiarum*	None	None	G5T2T3	S2.2	2.2
San Bernardino aster	*Symphyotrichum defoliatum*	None	None	G3	S3.2	1B.2
San Bernardino blue grass	*Poa atropurpurea*	None	None	G2	S2.2	1B.2
San Bernardino gilia	*Gilia leptantha ssp. leptantha*	None	None	G4T2	S2.3	1B.3
San Bernardino Mountains bladderpod	*Lesquerella kingii ssp. bernardina*	None	None	G5T1	S1	1B.1
San Bernardino Mountains dudleya	*Dudleya abramsii ssp. affinis*	None	None	G3T2	S2.2	1B.2
San Bernardino Mountains monkeyflower	*Mimulus exiguus*	None	None	G2	S2.2	1B.2
San Bernardino Mountains owl's-clover	*Castilleja lasiorhyncha*	None	None	G2	S2.2	1B.2
San Bernardino ragwort	*Packera bernardina*	None	None	G2	S2.2	1B.2
San Fernando Valley spineflower	*Chorizanthe parryi var. fernandina*	None	Endangered	G2T1	S1.1	1B.1
Sand evening-primrose	*Camissonia arenaria*	None	None	G4?	S2	2.2
Sand food	*Pholisma sonorae*	None	None	G2	S1.2	1B.2
Sanicle cymopterus	*Cymopterus ripleyi var. saniculoides*	None	None	G3G4T3Q	S1.2	1B.2

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Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Santa Ana River woollystar	*Eriastrum densifolium ssp. sanctorum*	None	Endangered	G4T1	S1	1B.1
Scalloped moonwort	*Botrychium crenulatum*	None	None	G3	S2.2	2.2
Scrub lotus	*Lotus argyraeus var. multicaulis*	None	None	G4?T1	S1.3	1B.3
Shockley's rock-cress	*Arabis shockleyi*	None	None	G3	S2.2	2.2
Short-joint beavertail	*Opuntia basilaris var. brachyclada*	None	None	G5T3	S3	1B.2
Short-sepaled lewisia	*Lewisia brachycalyx*	Endangered	None	G4G5	S3.2	2.2
Silver-haired ivesia	*Ivesia argyrocoma*	None	None	G2	S2.2	1B.2
Singlewhorl burrobrush	*Ambrosia monogyra*	None	None	G5	S2.2	2.2
Sky-blue phacelia	*Phacelia coerulea*	None	None	G5	S1.3	2.3
Slender-horned spineflower	*Dodecahema leptoceras*	None	Endangered	G1	S1	1B.1
Slender-petaled thelypodium	*Thelypodium stenopetalum*	None	Endangered	G1	S1.1	1B.1
Slender-stem bean	*Phaseolus filiformis*	None	None	G5	S1	2.1
Small-flowered androstephium	*Androstephium breviflorum*	None	None	G5	S1.2	2.2
southern jewel-flower	*Streptanthus campestris*	None	None	G2	S2.3	1B.3
Southern mountain buckwheat	*Eriogonum kennedyi var. austromontanum*	None	None	G4T2	S2.2	1B.2
Southern mountains skullcap	*Scutellaria bolanderi ssp. austromontana*	None	None	G4T2	S2.2?	1B.2
Spanish needle onion	*Allium shevockii*	None	None	G1	S1.3	1B.3
Tehachapi buckwheat	*Eriogonum callistum*	None	None	G1	S1	1B.1
Tehachapi monardella	*Monardella linoides ssp. oblonga*	None	None	G5T2	S2.2	1B.3
Thorny milkwort	*Polygala acanthoclada*	None	None	G4	S2.3	2.3
Tidestrom's milk-vetch	*Astragalus tidestromii*	None	None	G4G5	S2	2.2

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Common Name	Scientific Name	Regulatory Status[1]				
		Federal	State	G-Rank	S-Rank	CNPS
Tough muhly	*Muhlenbergia arsenei*	None	None	G5	S1S2	2.3
Tracy's eriastrum	*Eriastrum tracyi*	None	Rare	G1Q	S1.1	1B.2
Triple-ribbed milk-vetch	*Astragalus tricarinatus*	None	None	G1	S1.2	1B.2
Utah beardtongue	*Penstemon utahensis*	None	None	G4	S2.3	2.3
Utah glasswort	*Sarcocornia utahensis*	None	None	G4?	S1.2	2.2
Viviparous foxtail cactus	*Coryphantha vivipara var. rosea*	None	None	G5T3	S2.2	2.2
Western sedge	*Carex occidentalis*	None	None	G4	S2S3	2.3
White-bracted spineflower	*Chorizanthe xanti var. leucotheca*	None	None	G4T2	S2.2	1B.2
White-margined beardtongue	*Penstemon albomarginatus*	None	None	G2	S1	1B.1
Wiggins' croton	*Croton wigginsii*	None	Rare	G2G3	S1.2	2.2
Wright's bedstraw	*Galium wrightii*	None	None	G3G4	S1.2	2.3
Yucaipa onion	*Allium marvinii*	None	None	G1	S1.1	1B.1

[1] Regulatory Status

Federal = federally listed as endangered or threatened or candidate for listing

State = state-listed as endangered, threatened, or rare

G-Rank = California Natural Diversity Database (CNDDB) Element, Global Ranking:

G1 = Less than 6 viable element occurrences OR less than 1,000 individuals OR less than 2,000 acres

G2 = 6-20 element occurrences OR 1,000-3,000 individuals OR 2,000-10,000 acres

G3 = 21-80 element occurrences OR 3,000-10,000 individuals OR 10,000-50,000 acres

G4 = Apparently secure, but some threat or somewhat narrow habitat

G5 = Population or stand demonstrably secure to ineradicable due to being commonly found in the world

Note: Subspecies receive a T-rank attached to the G-rank; the G-rank then refers to the entire species, whereas the T-rank refers to the subspecies or variety.

S-Rank = CNDDB Element, State Ranking:

S1= Less than 6 occurrences OR less than 1,000 individuals OR less than 2,000 acres

S1.1 = very threatened

S1.2 = threatened

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S1.3 = no current threats known

S2 = 6-20 element occurrences OR 1,000-3,000 individuals OR 2,000-10,000 acres

S2.1 = very threatened

S2.2 = threatened

S2.3 = no current threats known

S3 = 21-80 element occurrences OR 3,000-10,000 individuals OR 10,000-50,000 acres

S3.1 = very threatened

S3.2 = threatened

S3.3 = no current threats known

S4 = Apparently secure, but some threat or somewhat narrow habitat (no threat rank)

S5 = Population or stand demonstrably secure to ineradicable due to being commonly found in California (no threat rank)

CNPS:

1B = CNPS List 1B – Rare, threatened, or endangered in California and elsewhere

0.1: Seriously endangered in California

0.2: Fairly endangered in California

0.3: Not very endangered in California

2 = CNPS List 2 – Rare threatened, or endangered in California, but more common elsewhere

0.1: Seriously endangered in California

0.2: Fairly endangered in California

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Appendix F

Vegetation Mapping: Overview and Recommendations

Based on the schedule for the draft DRECP to be ready for environmental review in December 2012, a comprehensive vegetation map would need to be completed by December 2011 in order to provide as full a picture of the vegetation community to the DRECP as logistically possible. Prompt funding will be required to initiate the alliance-level mapping and accuracy assessments necessary to create an acceptable DRECP vegetation map in this time frame. If schedule and funding do not allow for creation of a rigorous, accuracy-assessed, alliance-level vegetation map, to be used during DRECP development we recommend either (1) prioritizing such mapping on areas most likely to be affected by energy developments in the near term or (2) creating a mid-scale, interim vegetation map in the near term, as described below.

The current state of vegetation mapping is described in sections below. Different regions of the desert are covered by maps and databases that vary in approach, scale, accuracy, and schedule. We recommend rectifying the situation with a comprehensive, alliance-level vegetation map based on the CDFG mapping protocols as described below. Unfortunately, estimates to create a wall-to-wall, alliance-level vegetation and special features map for the western Mojave region are approximately 18 months once sufficient funding is provided to secure contract mapping, to augment mapping that could be accomplished through CDFG's Vegcamp efforts during the same time (T. Keeler-Wolf, personal communications). Given this is not possible under the DRECP schedule or available funding, vegetation alliance and special feature mapping should be prioritized within currently unmapped regions most likely to be affected by renewable energy developments, such as renewable energy study areas in the Western Mojave west of Barstow and around Owens Lake. Alternatively, a mid-scale, "interim" map could be created in the near term as a compromise that would be an improvement over the current situation, but would not have the fine resolution and accuracy that is ultimately desired.

Purpose of an "Interim" DRECP Map

It is extremely important to describe and map the vegetation types within the plan area, not only for their empirical value, but for translation into habitat modeling, site quality, and other important assessments. While the value of an interim vegetation map to accompany the DRECP process is extremely important, such a provisional map should not be considered the ultimate vegetation product in terms of the complete and accurate representation of all vegetation in the area of study. It lacks several significant components including a complete synoptic revision and simultaneous mapping of the entire area (e.g. it would represent a compilation of new and existing information with minor reformatting to allow for standardized representation and interpretation). It lacks a rigorous accuracy assessment, and thus can not be verified as reliable in all aspects of its attributes or spatial representation.

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However, the map should be sufficient to accomplish several important tasks. We expect the primary purpose of this map will be to display significant natural resource patterns not previously brought to light. This map would enable decision makers to better determine where to locate potential energy projects with minimal impact on the remaining natural and semi-natural vegetation, and help maintain an interlinked and sustainable network of corridors and large reserves containing all of the major unique and representative vegetation and habitat patterns within the study area.

Specifically the map and associated products should be able to do the following:

- Enable a regional analysis for the purposes of refining the site location of energy projects based on minimal impact to existing patterns of natural vegetation, and habitat and linkage evaluations for selected modeled species (appropriate to model with such vegetation and vegetation structure information as provided in the map layers).

- Enable choices between areas of vegetation/habitat with greater and lesser quality or ranking of vegetation based on size, uniqueness, spatial representation and quality.

The need for such a map is critical based upon how little accurate and useful information exists within currently available, broad-scale, generalized maps which is pertinent to actual "siting" of energy projects. There is an urgent need for at least a good mid-scale vegetation map, produced by photo-interpreters familiar with CA desert vegetation, with individually attributed polygons containing information on alliance or alliance group (new NVC mid-level hierarchy based on ecologically aggregated groups of alliances), basic structure (cover classes, height classes), and stand quality (attributes for degree of "roadedness", invasive exotic cover, and other easily interpreted attributes).

Despite the short time-frame before decisions need to be made (e.g., prior to the end of 2012), streamlined funding could enable the creation of a map covering all the previously non-mapped parts of the desert which focuses on the areas of interest by the energy development community. This map could be fairly easily merged with re-scaled, existing data-driven vegetation maps in the central and eastern Mojave and several of the large state and national parks. Thus, a wall-to-wall map of the area could be put together that would serve as a far better basis for making region-wide decisions than current broad-scale maps.

Existing Vegetation Mapping Efforts in the DRECP Plan Area

- **The Nature Conservancy's (TNC) Mojave Ecoregion Assessment.** TNC's map is one effort that might be considered as a DRECP "starting point" vegetation map. TheTNC vegetation map basically uses the 2006 California Landfire vegetation classifications with additional layers added by TNC based on their assessment work. However, the resolution of TNC's "Landfire +" map is too low (5 ha minimum mapping unit) to resolve special vegetation community areas at the alliance level, since many desert vegetation types rarely occur in stands greater than 5 hectares. Alliance level maps are essential to identify the desert vegetation features necessary to assess conservation actions under the DRECP.

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Some alliance level desert vegetation mapping has been done, though only for the Central and Eastern Mojave. The western Mojave area west of Barstow has not received any comprehensive vegetation mapping, especially at the alliance level. Since filling all the gaps in the alliance-level vegetation mapping efforts for the entire planning area may not be possible within the DRECP time frame, priority gap areas should be identified for immediate mapping efforts. Of the areas on the REAT Starting Point maps that are identified as DRECP renewable energy study areas, the Western Mojave lands west of Barstow and around Owens Lake represent highest priority DRECP vegetation mapping areas, because they lack alliance-level vegetation mapping data and have been identified as renewable energy study areas.

- **The State Mapping Program**. The State Mapping Program, headed by Dr. Todd Keeler-Wolf (CDFG), has been mapping large areas of the state over the last several years using the National Vegetation Classification System (NVCS), tailored for California (and as reflected in the Manual of California). While the mapping effort to date is not comprehensive, it might be considered as a baseline/starting point for vegetation mapping and/or mapping of unique features for the DRECP. This is not the same mapping as reflected in the CDFG maps presented at the DRECP workshop in April 2010. CDFG's mapping efforts have slowed in the past few years due to budget constraints, therefore additional mapping of desert areas by CDFG (or others using the same methodology) should be high priority for funding.

  In addition to vegetation mapping, the various efforts under this program have mapped:

  - Playas
  - Alkali sinks
  - Wash systems
  - Active dunes
  - Unique (vegetation) stands
  - Ironwood (one example of a vegetation association of interest)
  - Mud hills
  - Rock outcrops
  - Non-native grasses, including (in Anza-Borrego): Schismus, red brome, and cheatgrass

  The state-based vegetation mapping efforts are detailed and based on statistical analyses of field sampling data to produce a floristically-based vegetation classification scheme. This is followed by aerial photo interpretation to produce a vegetation map, and some level of accuracy assessment. Because the classification follows the NVCS, categories can be aggregated into a higher (broader) level of classification, as needed. Use of a NVC-based system may allow for a more seamless transition across state boundaries if adjacent states use classifications that also follow the NVCS, regardless of level of detail. In addition, the data collection for the state program is structured to obtain some suitability information (per CWHR protocols) for vertebrate species.

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Detailed Information Concerning State Mapping Efforts

- **Mojave Desert Ecosystem Program**: Central Mojave Vegetation Database (Kathryn Thomas, USGS, Todd Keeler-Wolf, CDFG; Janet Franklin, SDSU; and Peter Stine; USFS; 2004).

  The database for this project includes (among other things):

  - Vegetation map of the Central Mojave Desert (eastern Mojave Desert in California)
  - Central Mojave Environmental Type Grid: Environmental classes defined to stratify the study area to allocate the vegetation relevé samples,
  - Mojave Summer Precipitation Grid,
  - Mojave Winter Precipitation Grid,
  - Mojave January Average Minimum Temperature Grid,
  - Mojave July Average Maximum Temperature Grid,
  - Central Mojave Special Features Map: Potential and known locations of special vegetation features, with less than 5 ha extent
  - Other attributes of this mapping effort (taken directly from the report):
  - Covers approximately 60% (5 million hectares) of the Mojave Desert in California
  - Mapped areas represent a majority of public lands in the study area, with an emphasis on certain DOD and Department of Interior lands
  - Includes primarily polygon data although certain rare or localized types are mapped as points
  - Most vegetation types are represented at the alliance level
  - Datum: Horizontal World Geodetic Systems of 1984 (WGS84), which is equivalent to North American Datum of 1983 (NAD83), Universal Transverse Mercator (UTM) projection
  - Vertical - National Geodetic Vertical Datum of 1929
  - Accuracy: 80% thematic accuracy or confidence level

  The "Central Mojave Special Features" map layer associated with this Mojave Desert Ecosystem Program is described as mapping

  "point locations for known or potential places where vegetation alliances or unique stands with less than 5 hectares (ha) of spatial extent occur. Many vegetation types in the Mojave Desert rarely, if ever, occur in stands greater than 5 ha in area. The target standard for the Central Mojave Vegetation Map is a 5 ha minimum mapping unit (MMU), and the methods used to label the map preclude mapping these special features. However, it is important to note the known or potential location of vegetation alliances for future mapping at finer spatial resolution.

  Purpose: The Central Mojave Special Features Map (spec_feat.e00) serves as a template for more comprehensive development of a database describing rare or localized vegetation types, habitats, or plant species."

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As this quote from the Special Features GIS layer metadata file explains, Thomas et al. created this map layer to serve as a sampling of the type of higher resolution vegetation map currently sought today: one that could best inform a comprehensive desert conservation planning process. This layer could serve as a model for how to map the priority gap areas during a DRECP vegetation mapping effort, where this phase would include collecting, analyzing, calibrating, and mapping existing data sets and developing new datasets from fresh field efforts.

Links:

Map (BIOS): http://imaps.dfg.ca.gov/viewers/biospublic/app.asp?zoomtoBookmark=815

Report: https://nrmsecure.dfg.ca.gov/FileHandler.ashx?DocumentID=13890

GIS dataset: http://www.mojavedata.gov/datasets.php?&qclass=veg

- **Vegetation Mapping of Anza-Borrego Desert State Park and Environs**. Prepared by Natural Heritage Division California Department of Fish and Game, 1998.

  Although this mapping effort may need to be updated, it would provide good baseline data for areas that have not changed significantly since the initial data collection efforts. The study area for this mapping includes ABDSP, but also extends beyond the park boundaries to include much of the jointly managed public lands southwest of the park and portions of BLM land east of the Park.

  Within the study area, 501 vegetation samples were taken and over 23,000 polygons were delineated and attributed. A total of 94 mapping units were used to depict the vegetation.

  Links:

  Map (BIOS): http://imaps.dfg.ca.gov/viewers/biospublic/app.asp?zoomtoBookmark=814

  Report: http://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=18246

- **Other Relevant Mapping Efforts**. Other existing vegetation map efforts are listed below that could help fill in gaps in the priority western areas of the plan boundries; however, new field efforts will also be necessary to generate anything approaching a complete picture of the vegetation in the remaining other areas of the planning area.

  - Vegetation Mapping of Western Riverside County, California. Report on Alliances prepared by California Native Plant Society, 2006; vegetation map prepared by AIS.

    The effort may include a small portion of the desert. The report describes methodology, results, and final classification system (based on NVCS) for study area. It does not include a vegetation map (contracted separately). As with other mapping efforts under this program, field survey data were analyzed statistically to come up with a floristically-based classification. Vegetation mapping was done by interpretation of ortho-rectified, aerial photographs for vegetation signatures in color infrared (CIR) and in natural color (imagery flown in winter or summer). A detailed map was produced through the following process: 1) hand-delineation of polygons on base CIR imagery, 2) digitization of polygons, and 3) attribution of the vegetation types and overstory cover values. The map was created (apparently by AIS, Aerial Interpretation Systems), in a Geographic Information System (GIS) digital format, as was the database of field surveys, but copies have not yet been located.

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Report: http://www.cnps.org/cnps/vegetation

- "Specialty Reserve Areas" were mapped during the Western Mojave Plan (WEMO) development. These maps appeared in Appendix J of an Administrative Review draft of the WEMO, but did not survive the internal review stage. There are areas identified as Specialty Reserve Areas (for flora and fauna) that would be useful for the DRECP process. It is unclear whether this information was digitized. TNC and DFG are the two GIS points of contact making this information accessible to the REAT for inclusion in the DRECP.
- Edwards AFB and Ft. Irwin vegetation maps. These maps have been compiled by Dave Charlton. These may be very useful to help extrapolate vegetation information outward from those bases if the DRECP can obtain access to the data from DOD. Currently, Julie Evens, CNPS Vegetation Program Director, and Todd Keeler-Wolf, CDFG Senior Vegetation Ecologist, have descriptions of the vegetation maps but not the data sets themselves nor GIS layers.
- Owens Lake area vegetation maps. These maps have been created by Mark Bagley for LADPW. If this agency allows access to the vegetation map data for the DRECP, this information would be very useful for those "brown areas" around Owens Lake on the REAT Starting Point maps.
- Saline wetlands and meadows in the Owens Valley. These areas have been mapped by Sally Manning of the Inyo County Water Department. This info could supplement a DRECP vegetation map effort.
- Springs and seeps in the Mojave Desert. These features have been mapped by Andy Sanders at the U.C. Riverside (UCR) herbarium, and it would be worthwhile to investigate what data and map layers he might have that could improve the DRECP vegetation map.

The Central Mojave Desert Report references two other currently ongoing mapping projects: the USGS/NPS Park Mapping Program in Joshua Tree National Park and the Southwest Regional Gap Analysis Program. These efforts will potentially provide suitable mapping for the southern Mojave and portions of the eastern Mojave (those portions in Arizona, Nevada, and Utah). Additional areas in the eastern Mojave that are not covered by any of these mapping projects are Ward Valley and portions of the Colorado River Corridor.

- Joshua Tree National Park. This vegetation characterization program is a cooperative effort by USGS and NPS to classify, describe, and map vegetation communities in Joshua Tree National Park. The effort follows the NVCS. Mapping standards include a minimum mapping unit of 0.5 hectares and classification accuracy of 80% for each map class. Final products will include a vegetation classification and vegetation maps. The field work is apparently complete but data needs to be processed and a map produced.
- Southwest Regional Gap Analysis Program: This program does not include California, but does include bordering states, and provides a seamless land cover between states. Land cover modeling was done using a decision tree classifier based on 93,000 field samples. While the scale of this mapping is coarser than the current California StateMapping project

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efforts, it does follow the NVC hierarchy, so different efforts can be cross-reference or cross-walked.

- Death Valley National Park. This mapping project is being conducted in the same manner (and under the same program) as described above for Joshua Tree National Park. This effort is in-progress but not yet complete.
- Death Valley National Park Travertine Springs Complex Vegetation: Vegetation polygons and point data are available for mapped features, and the mapping was conducted using the NVCS classification.

  Reference: Thomas, K.A. 2006. Death Valley National Park Travertine Springs Complex Vegetation. US Geological Survey Southwest Biological Science Center. Technical Report.

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Appendix G

Background Documents and Maps Concerning Conservation Planning in California Deserts

Agency Management Plans

- Bureau of Land Management
  - Imperial Sand Dunes Recreation Area Management Plan (2010) http://www.blm.gov/ca/st/en/fo/elcentro/recreation/ohvs/isdra/dunesinfo/docs/isdramp.html
  - Amargosa River Area of Critical Environmental Concern Implementation Plan (2007) http://www.blm.gov/ca/pdfs/barstow_pdfs/amargosa_ea/Index.pdf
  - California Desert Protection Act (1994). http://www.dmg.gov/documents/NOT_CA_Desert_Protection_Act_of_1994_103194.pdf
  - California Desert Conservation Area Plan (1980 as amended) http://www.dmg.gov/documents/PLN_CA_Desert_Cons_Area_BLM_101299.pdf
  - Proposed Northern and Eastern Mojave Desert Management Plan (NEMO), Amendment to the California Desert Conservation Area Plan, Final Environmental Impact Statement, and Record of Decision. http://www.blm.gov/ca/news/pdfs/nemo2002/
  - Proposed Northern and Eastern Colorado Desert Coordinated Management Plan and Final Environmental Impact Statement. http://www.blm.gov/ca/st/en/fo/cdd/neco.html
- National Park Service
  - Death Valley National Park, General Management Plan (2002) http://www.nps.gov/deva/parkmgmt/upload/GMP_001.pdf
  - Joshua Tree National Park
    - Joshua Tree Centennial Strategy (2007) http://www.nps.gov/jotr/parkmgmt/upload/JOTR_Centennial_Strategy.pdf
    - Fire Management Plan (2005)

      http://www.nps.gov/jotr/parkmgmt/upload/fire.pdf
    - Backcountry & Wilderness Management Plan (2000) http://www.nps.gov/jotr/parkmgmt/bcmp.htm
    - General Management Plan (1995?)

      http://www.nps.gov/jotr/parkmgmt/gmp.htm
    - Mojave National Preserve, General Management Plan 2002

      http://www.nps.gov/moja/parkmgmt/gmp.htm

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- State Parks
  - Anza-Borrego Desert State Park General Plan and Environmental Impact Report (2005) http://www.parks.ca.gov/default.asp?page_id=21314
  - Ocotillo Wells State Vehicular Rcreation Area General Plan (1982) http://www.parks.ca.gov/pages/21299/files/439.pdf
  - Red Rock Canyon State Park General Plan (1981; revision in progress) http://www.parks.ca.gov/pages/21299/files/577.pdf
- Multi-agency
  - Mojave Desert Ecosystem Program (MDEP) (central data warehouse)

    http://www.mojavedata.gov/

Conservation Planning Documents

- A Framework for Effective Conservation Management of the Sonoran Desert in California (2009) http://consbio.org/what-we-do/a-framework-for-effective-conservation-management-of-the-sonoran-desert-in-california
- An Ecological Analysis of Conservation Priorities in the Sonoran Desert Ecoregion (2000) http://azconservation.org/dl/TNCAZ_Ecoregions_Assessment_Sonoran Desert.zip
- Desert Bird Conservation Plan (2009) http://www.prbo.org/calpif/htmldocs/desert.htm
- Draft California Desert Conservation Vision (2006) [Document available]
- California Desert Conservation Vision: Workshop Agenda, Desert Conservation Vision and Goals, and Survey Summary (2006) [Document available]
- Ecoregion-based Conservation in the Mojave Desert (2001) http://azconservation.org/dl/TNCAZ_Ecoregions_Assessment_Mojave_Desert.zip
- Sonoran Desert Conservation Plan (Arizona) http://www.pima.gov/CMO/SDCP/
- Sonoran Joint Venture Bird Conservation Plan (2006) http://www.sonoranjv.org/planning/cons_plan/Ver1_Chapter_Oct2006/SJV_Conservation_Plan_Vers-1-0.pdf

General Plans/Community Plans

- Imperial County General Plan and Community Plans http://www.icpds.com/?pid=829 and http://www.icpds.com/?pid=618
- Kern County General Plan and Community Plans http://www.co.kern.ca.us/planning/pdfs/kcgp/KCGP.pdf
- Riverside County General Plan and Community Plans

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http://www.rctlma.org/genplan/content/gp.aspx

- San Diego County General Plan and Community Plans
  http://www.sdcounty.ca.gov/dplu/gpupdate/draftgp.html

HCPs/MSCPs

- California Desert Conservation Area Resource Management Plan (CDCA Plan) (1980 reprinted in 1999).
  http://www.blm.gov/pgdata/etc/medialib/blm/ca/pdf/cdd/cdcaplan.Par.15259.File.dat/CA_Desert_.pdf
- Lower Colorado River Multi-Species Conservation Program (2004).
  http://www.lcrmscp.gov/publications/VolumeII.pdf
- Final Environmental Impact Report and Statement for the West Mojave Plan. A Habitat Conservation Plan and California Desert Conservation Area Plan Amendment (2005).
  http://www.dmg.gov/subdocs.php?item=westmojave
- Coachella Valley Multiple Species Habitat Conservation Plan/Natural Community Conservation Plan (2007).
  http://www.cvmshcp.org
- Salton Sea Ecosystem Restoration Program: Draft Programmatic Environmental Impact Report (February 14, 2007) and Final Programmatic EIR (June 26, 2007).
  http://www.saltonsea.water.ca.gov/PEIR/final/Cover_Vol_I.pdf

Corridors/Linkages

- South Coast Missing Linkages: A Wildland Network for the South Coast Ecoregion (no date) (http://www.scwildlands.org/reports/SCMLRegionalReport.pdf)
- South Coast Missing Linkages Project: A Linkage Design for the Joshua Tree – Twentynine Palms Connection (2008) (http://www.scwildlands.org/reports/JT_TP_Connection.pdf)
- South Coast Missing Linkages Project: A Linkage Design for the Peninsular-Borrego Connection (2006) (http://www.scwildlands.org/reports/SCML_PeninsularBorrego.pdf)
- South Coast Missing Linkages Project: A Linkage Design for the San Bernardino-Granite Connection (2005) (http://www.scwildlands.org/reports/SCML_SanBernardino_Granite.pdf)
- South Coast Missing Linkages Project: A Linkage Design for the San Bernardino-Little San Bernardino Connection (2005)
  (http://www.scwildlands.org/reports/SCML_SanBernardino_LittleSanBernardino.pdf)
- South Coast Missing Linkages Project: A Linkage Design for the San Bernardino-San Jacinto Connection (2005)
  (http://www.scwildlands.org/reports/SCML_SanBernardino_SanJacinto.pdf

Desert Renewable Energy Conservation Plan

- Renewable Energy in California: Implementing the Governors Renewable Energy Executive Order (Joint Public Workshop 2009)

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http://www.energy.ca.gov/33by2020/documents/2009-03-12_meeting/presentations/Department_of%20Fish_and_Game.PDF

- Memoradum of Understanding between the California Department of Fish and Game, The California Energy Commission, The Bureau of Land Management, and the U.S. Fish and Wildlife Service Regarding the Establishment of the California Renewable Energy Action Team (2008) http://www.blm.gov/pgdata/etc/medialib/blm/ca/pdf/pa/energy.Par.76169.File.dat/RenewableEnergyMOU-CDFG-CEC-BLM-USFWS-Nov08.pdf

Solar Energy Projects

- Solar Energy Development Programmatic EIS Information Center http://solareis.anl.gov/ including:
  - Summary of Public Scoping Comments received during the scoping period for the Solar Energy Development Programmatic Environmental Impact Statement. (2008). http://solareis.anl.gov/documents/docs/Scoping_Summary_Report_Solar_PEIS_Final.pdf
  - Map – Concentrating Collector Solar Resource on All BLM Administered Land http://solareis.anl.gov/documents/maps/sol010.pdf
  - Map – Tilted Photovoltaic Panel Solar Resource on All BLM Administered Land http://solareis.anl.gov/documents/maps/sol015.pdf
  - Map – Solar Energy Study Areas for In-Depth Study in California http://solareis.anl.gov/eis/maps/index.cfm and http://solareis.anl.gov/documents/maps/studyareas/Solar_Study_Area_CA_Ltt_7-09.pdf

Species Recovery Plans/Recovery Goals/Implementation Progress

- Desert Pupfish
  - Desert Pupfish Recovery Plan Implementation Progress. (http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=E044
  - U.S. Fish and Wildlife Service. 1993. Desert Pupfish Recovery Plan. Phoenix, Arizona. 67 pp. http://www.fws.gov/southwest/es/Arizona/Documents/RecoveryPlans/DesertPupfishRecoveryPlan.pdf
  - Desert Pupfish – Critical Habitat Designation (1986). http://ecos.fws.gov/docs/federal_register/fr1102.pdf

- MohaveTui Chub
  - U.S. Fish and Wildlife Service. 1984. Recovery Plan for the Mohave Tui Chub, *Gila bicolor mohavensis*. U.S. Fish and Wildlife Service, Portland, Oregon. 56 pp. http://ecos.fws.gov/docs/recovery_plan/840912.pdf

- Bonytail Chub
  - U.S. Fish and Wildlife Service. 2002. Bonytail (*Gila elegans*) Recovery Goals: amendment and supplement to the Bonytail Chub Recovery Plan. U.S. Fish and Wildlife

Peer Draft

Service, Mountain- Prairie Region (6), Denver, Colorado. http://ecos.fws.gov/docs/recovery_plan/060727a.pdf

- Razorback Sucker
  - U.S. Fish and Wildlife Service. 2002. Razorback sucker (*Xyrauchen texanus*) Recovery Goals: amendment and supplement to the Razorback Sucker Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado. http://ecos.fws.gov/docs/recovery_plan/060727c.pdf
- Desert Slender Salamander
  - U.S. Fish and Wildlife Service. 2009. Desert slender salamander *(Batrachoseps major aridus);* 5-Year Review: Summary and Evaluation. Carlsbad, California. 16 pp. http://ecos.fws.gov/docs/five_year_review/doc2600.pdf
  - Desert Slender Salamander Recovery Plan – Implementation Progress. https://ecos.fws.gov/roar/pub/planImplementationStatus.action?documentId=400076
  - U.S. Fish and Wildlife Service, California Department of Fish and Game, and Hidden Palms Ecological Reserve Committee. 1982. Desert Slender Salamander Recovery Plan. http://ecos.fws.gov/docs/recovery_plan/820812.pdf
- Arroyo Southwestern Toad
  - U.S. Fish and Wildlife Service. 1999. Arroyo southwestern toad (*Bufo microscaphus californicus*) recovery plan. U.S. Fish and Wildlife Service, Portland, Oregon. vi + 119 pp. http://ecos.fws.gov/docs/recovery_plan/990724.pdf
- Coachella Valley Fringe-tailed Lizard
  - Coachella Valley Fringe-tailed Lizard Recovery Plan Action Status. https://ecos.fws.gov/roar/pub/planImplementationStatus.action?documentId=400170
  - U.S. Fish and Wildlife Service. 1984. Coachella Valley Fringe-toed Lizard Recovery Plan. U.S. Fish and Wildlife Service, Portland, OR. 60 pp. http://ecos.fws.gov/docs/recovery_plan/850911b.pdf
- Desert Tortoise
  - U.S. Fish and Wildlife Service. 2008. Draft revised recovery plan for the Mojave population of the desert tortoise (*Gopherus agassizii*). U.S. Fish and Wildlife Service, California and Nevada Region, Sacramento, California. 209 pp. http://www.fws.gov/nevada/desert_tortoise/documents/recovery_plan/DraftRevRP_Mojave_Desert_Tortoise.pdf
  - Desert Tortoise Recovery Plant Action Status. https://ecos.fws.gov/roar/pub/planImplementationStatus.action?documentId=1002909
  - Determination of Critical Habitat for the Mojave Population of the Desert Tortoise (1994). http://ecos.fws.gov/docs/federal_register/fr2519.pdf
- Inyo California Towhee
  - U.S. Fish and Wildlife Service. 2008. Inyo California Towhee (*Pipilo crissalis eremophilus*) [=Inyo Brown Towhee (*Pipilo fuscus eremophilus*)]; 5-Year Review:

Peer Draft

Summary and Evaluation. U.S. Fish and Wildlife Service, Ventura, California. September.

- U.S. Fish ad Wildlife Service. 1998. Recovery Plan for the Inyo California Towhee. U.S. Fish and Wildlife Service, Portland, Oregon. 32 pp.
- Determination of Threatened Status and Critical Habitat for the Inyo Brown Towhee (1987). http://ecos.fws.gov/docs/federal_register/fr1306.pdf

- Least Bell's Vireo
  - U.S. Fish and Wildlife Service. 1998. Draft Recovery Plan for the Least Bell's Vireo (*Vireo bellii pusillus*). U.S. Fish and Wildlife Service, Portland, Oregon. 139 pp. http://ecos.fws.gov/docs/recovery_plan/980506.pdf

Southwestern Willow Flycatcher

- U.S. Fish and Wildlife Service. 2005. Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the Southwestern Willow Flycatcher (*Empidonax traillii extimus*); Final Rule. http://www.fws.gov/southwest/es/arizona/Documents/SpeciesDocs/SWWF/CH_Final_Oct05/FR_FinalCH_SWWF.pdf
- U.S. Fish and Wildlife Service. 2002. Southwestern Willow Flycatcher Recovery Plan. Albuquerque, New Mexico. i-ix+ 210 pp., Appendices A-O. http://www.fws.gov/southwest/es/arizona/SWWF_RP.htm

Yuma Clapper Rail

- U.S. Fish and Wildlife Service. 2009. Yuma Clapper Rail (*Rallus longirostris yumanensis*) Recovery Plan. Draft First Revision. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, New Mexico. http://ecos.fws.gov/docs/recovery_plan/Draft%20Yuma%20Clapper%20Rail%20Recovery%20Plan,%20First%20Revision.pdf
- Yuma Clapper Rail, 5 year review (2000-2005). 2006. http://ecos.fws.gov/docs/five_year_review/doc782.pdf

Amargosa Vole

- Amargosa Vole Recovery Plan Action Status. https://ecos.fws.gov/roar/pub/planImplementationStatus.action?documentId=400200
- U.S. Fish and Wildlife Service. 1997. Amargosa Vole (*Microtus californicus scirpensis*) Recovery Plan. Portland, Oregon. 43 pp. http://ecos.fws.gov/docs/recovery_plan/970915.pdf

Palm Springs Round-tailed Ground Squirrel (not listed)

- U.S. Fish and Wildlife Service. 2009. Species Assessment and Listing Priority Assignment Form. *Xerospermophilus tereticaudus chlorus* (formerly *Spermophilus tereticaudus chlorus*); Palm Springs round-tailed ground squirrel.

Peninsular Bighorn Sheep

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- U.S. Fish and Wildlife Service. 2009. Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for Peninsular Bighorn Sheep and Determination of a Distinct Population Segment of Desert Bighorn Sheep (*Ovis canadensis nelsoni*); Final Rule. http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=2009_register&docid=fr14ap09-20
- U.S. Fish and Wildlife Service. 2000. Recovery plan for bighorn sheep in the Peninsular Ranges, California. U.S. Fish and Wildlife Service, Portland, OR. Xv + 251 pp. http://ecos.fws.gov/docs/recovery_plan/001025.pdf

Plants

- Olsen, T.G. 2003. Carbonate Habitat Management Strategy. Prepared for the San Bernardino National Forest Association. 87 pp. + appendix. http://www.fs.fed.us/r5/scfpr/projects/lmp/docs/carbonate-strategy.pdf
- U.S. Fish and Wildlife Service and M. DeDecker. 1982. The Eureka Valley Dunes Recovery Plan. Independence, CA. 84 pp. http://ecos.fws.gov/docs/recovery_plan/Eureka%20Valley%20Dunes%20Recovery%20Plan.pdf
- U.S. Fish and Wildlife Service. 1998. Endangered and Threatened Wildlife and Plants; Determination of Endangered or Threatened Status for Five Desert Milk-vetch taxa from California. FR 63(193):53596-53615. http://www.fws.gov/endangered/pdfs/FR/f981006.pdf
- U.S. Fish and Wildlife Service. 2005. Endangered and threatened wildlife and plants; designation of critical habitat for *Astragalus lentiginosus* var. *coachellae* (Coachella Valley Milk-Vetch); Final Rule. FR 70(239):74112-74136. http://ecos.fws.gov/docs/federal_register/fr4492.pdf

Combined (Plants/Animals)

- U.S. Fish and Wildlife Service. 1998. Owens Basin Wetland and Aquatic Species Recovery Plan, Inyo and Mono Counties, California. Portland, Oregon. http://ecos.fws.gov/docs/recovery_plan/980930b.pdf

Climate Change and Sensitive Species

- A Framework for Categorizing the Relative Vulnerability of Threatened and Endangered Species to Climate Change (2009) http://oaspub.epa.gov/eims/eimscomm.getfile?p_download_id=492883

Maps

- Mojave Desert – Last Great Places and Conservation Portfolio Areas (The Nature Conservancy) [Available]
- Colorado Desert Strategic Visioning Project:
  - Colorado Desert Community Buffers [Available]
  - Colorado Desert Natural Resources [Available]
  - Colorado Desert Cultural Areas [Available]
  - Colorado Desert Recreation Areas [Available]

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Miscellaneous:

- Mojave Desert Science Symposium http://www.dmg.gov/mdss/index.php
- Desert Managers Group http://www.dmg.gov/index.php
  - Science Research Projects in the California Deserts http://www.dmg.gov/science/projectlist.php?arrange=area

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TRANSLOCATION OF DESERT TORTOISES(MOJAVE POPULATION) FROM PROJECT SITES: PLAN DEVELOPMENT GUIDANCE
U.S. Fish and Wildlife Service
August 2010

The following guidance provided by the U.S. Fish and Wildlife Service (USFWS) is based on the best scientific information currently available and will be updated as new information and data are obtained. This guidance is complementary to existing protocols for the desert tortoise (*Gopherusagassizii*)that should be referenced when planning and implementing surveys, translocation plans, and other activities involving this species. To ensure that you are referring to the most current guidance and protocols, contact your local USFWS field office or see http://www.fws.gov/ventura/speciesinfo/protocols_guidelines/, where the following can be accessed: Pre-project Survey Protocol, Desert Tortoise Field Manual (includes Pre-project Survey Protocol, Clearance Survey Guidelines, Handling Guidelines, and Exclusion Fence Specifications), Qualifications and Requirements for Authorized Biologists, and Desert Tortoise Exclusion Fence Specifications. In addition, please refer to the technical paper prepared by USFWS's Desert Tortoise Recovery Office (DTRO) on translocation of desert tortoises (in prep.) for the scientific underpinnings of the recommendations contained herein.

The purpose of this document is to provide guidance for the development of project-specific translocation plans for activities that may impact desert tortoises when avoidance of these impacts is not feasible and adverse effects of the incidental take of desert tortoises associated with the proposed action need to be minimized. Prior to drafting a translocation plan, however, project proponents should identify, review, and consider all potential measures to avoid adverse effects to desert tortoises at the project site. **If translocation can be justified as the most appropriate course of action, this document should be used as an outline that, when combined with project-specific input from the USFWS and other permitting agencies, will facilitate the completion of a translocation plan.**

The implementation of any translocation will necessitate take of desert tortoises in some form. Take is defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or to attempt to engage in any such conduct. Section 9 of the Endangered Species Act of 1973, as amended, and Federal regulation pursuant to section 4(d) of the Act prohibit the take of endangered and threatened species, respectively, without special exemption. Consequently, translocation of desert tortoises may be undertaken only when authorized by the USFWS through the issuance of an incidental take permit pursuant to section 10(a)(1)(B) of the Act, or if an exemption against the prohibitions against take is granted through the issuance of a biological opinion that contains an incidental take statement under the authorities of section 7(a)(2) of the Act. The translocation plan, after approval by the USFWS, would be incorporated into the project design or included in the terms and conditions of the USFWS's biological opinion or incidental take permit. **In general, activities from Step 6 through Step 10 of this guidance canonly be conducted in accordance with an incidental take permit or biological opinion.**

In addition to this guidance, project proponents should confer with the respective State wildlife agencies within the range of the Mojave population of the desert tortoise where compliance with State laws is mandated or different survey and translocation protocols exist. Collection or take permits may also be required by other Federal agencies or by State laws and regulations.

We have summarized the actions associated with translocation in chronological order. There may be different recommendations for projects that expect to translocate desert tortoises a distance greater than 500 meters (m) from the point of collection versus those that expect to release desert tortoises within 500 mof the point of collection. Table 1 below provides a quick reference of the various recommendations based on number of desert tortoises expected to be moved and translocation distance. Because any given project may have unique circumstances, we recommend project proponents and the lead action agency work closely with the appropriate USFWS field office and State wildlife agenciesas early in the planning process as possible to determine which of the components and to what degree each of the following should be includedin project-specific translocation plans.

1.Determine need for translocation of desert tortoises based of the long-term compatibility of the proposed land use with desert tortoise occurrence (refer to *Translocation of Desert Tortoises (Mojave Population) from Project Sites: A Technical Paper*).

2. Estimate the number of desert tortoises that will be affected at the project site. Conduct desert tortoise surveys according to the most recent USFWS Pre-project Survey Protocol(accessed at the website above) and include data on carcasses observed during surveys. Surveys should be conducted during the desert tortoise's most active periods (*i.e.*, typically April 1 through May 31 or September 1through October 15 when air temperatures are below 40°C (104°F),which should be verified by activity in the field.Temperature should be measured in the shade and protected from the wind at a height of 5 centimetersabove the ground.). These data will be used to estimate the number of desert tortoises expected to be impacted by the project;assist in identifying potential recipient (translocation) sites based on the density estimates; and, if applicable, determine the minimum number of resident and control desert tortoises needed for monitoring purposes. If out-of-season surveys, probabilistic sampling, or non-protocol surveys are proposed for the project site, approval from the USFWS and State wildlife agenciesshould be obtained prior to conducting any surveys; this increases the likelihood that survey results will be accepted.

3. Identify potential recipient and control sites[1] for projects. Planning should be done in coordination with Federal and State wildlife and land management agencies, and approval from the landowner/manager for use of the sites should be obtained. Recipient sites should be at least equal in size to the project site.The project site and recipient site should be within 40 kilometers (km) of one another with no natural barriers to movement betweenthem,as thedesert tortoises at the two sites were likelypart of a larger mixing population and similar genetically. In addition, the site should support desert tortoise habitatthat is equivalent in type/quality to the project site, suitable for all life stages, have no designated rights-of-way (ROWs) or other encumbrances, and be managed for conservation so that potential threats from future impacts are precluded in perpetuity.

Selection of potential recipient sites should focus on lands where desert tortoise populations have been depleted or extirpated yet still support suitable habitats. These may include lands adjacent to highways or within designated critical habitator lands identified as Desert Tortoise Conservation Areas (TCAs) in the revised recovery plan for the species (*e.g.*, Desert Wildlife Management Areas, Areas of Critical Environmental Concern, National Park Service lands, designated critical habitat, etc.); lands outside TCAs that are important for maintaining habitat

[1] See Table 1 for circumstances when identification of recipient and control sites is necessary.

and population connectivity and that are not subject to future impacts or are a minimum of 10km from areas expected to be developed; or lands where management actions are currently being tested. In addition, recipient sites should be at least 15km from major unfenced roads or highways; distances from roads may be reduced if the proposed action includes provisions to install desert tortoise exclusion fencing as a minimization measure.

Some recipient sites may need to be temporarily or permanently fenced (partially or completely) if adjacent areas (*e.g.*, adjacent to highways) are not protected or desert tortoise movements need to be restricted. We recommend that more than one potential recipient site be identified during planning to ensure that disease status, desert tortoise densities, or other factors do not prevent the use of the potential site(s).As stated above, the selection of the recipient sites should be coordinated with Federal and State wildlife and land management agencies.

Potential control sites should be equivalent in habitat type/quality, desert tortoise population size/structure, and disease status as the recipient sites. Control sites should not have been previously used as a recipient site for other projects and should be a minimum distance of 10km from the project site if the recipient site is unfenced or no substantial anthropogenic or natural barrier exists to prevent the interaction of control, resident, and translocateddesert tortoises.

4. Estimate desert tortoise densities at agreed-upon recipient and controlsites[1]. Conduct desert tortoise surveys according to the most recent USFWS Pre-project Survey Protocol and include data on carcasses observed during surveys. Surveys should be conducted during the desert tortoise's most active periods (*i.e.*, typically April 1 through May 31 or September 1through October 15when air temperatures are below 40°C (104°F),which should be verified by activity in the field).**Desert tortoises should be closely observed but not handled at this time**.

Projected density after translocation at the recipient sites (residents plus translocated juvenile, subadult, and adult individuals) should not exceed 130% of the mean density detected in the respective desert tortoise recovery unit. In some circumstances it may be most appropriate to use site-specific density information, thus close coordination with Federal and State wildlife and land management agencies is recommended. Contact the USFWS for most current data on desert tortoise densities within each recovery unit.

Any incidental observations of signs of disease should be documented during the surveys of these sites. Signs of infection from upper respiratory tract disease are as follows:

- nasal or moderate-to-severe ocular discharge
- eroded nares
- partially or completely occluded nares

Signs of dried nasal and ocular discharge must be obvious and should not be confused with dried dirt or mud on the beak and nares from recent rain events.

5. Develop thetranslocation plan in close coordination with USFWS, State wildlife agencies, and land management agencies. Note that the translocation recommendations vary according to the number and distance desert tortoises are expected to be moved and many of the details may be project specific (Table 1).We recommend that the translocation plan and proposed project be approved and permits secured prior to beginning steps 6-10. **Activities requiring the handling of desert tortoises may be conducted only under the authorities of an incidental take permit or biological opinion and applicable State permits.**

6. Confirm desert tortoise densities at the recipient and control sites[1] as*in situ* health assessment sampling is conducted and transmitters are attached.The methods used to confirm desert tortoise densities at the recipient and control sites should be consistent with the USFWS Pre-project Survey Protocol(for very large sites a sampling scheme rather than a complete survey may be designed in coordination withUSFWS and State wildlife agencies), and the appropriate level of health assessments should be conducted based on the distance between the point of collection on the project site and the identified recipient site.Desert tortoises that will be monitored should be assigned a unique identifier (provided by USFWS) and fitted with a transmitter. Again, projected density after translocation at the recipient sites should not exceed 130% of the mean density detected in the respective desert tortoise recovery unit or otherwise determined by the Federal and State wildlife and land management agencies.

Health assessments should be performed on all desert tortoises encountered during the surveys at the recipient and control sites.Results from health assessments, including blood work, will be valid for 1 year from the date that the assessment was conducted. Additional health assessments of the recipient and control desert tortoises may be required if desert tortoises are not translocatedto the recipient site within 1 year of the original assessment dates.Handling of resident and control desert tortoises in order to perform health assessments and attach transmitters should be done in accordance with protocols in the Desert Tortoise Field Manual; particular attention should be paid to temperature thresholds and eliminating the spread of disease.

When the recipient site will be receivingdesert tortoises that will be moved less than500m from the point of collection and there are no barriers to impede natural desert tortoise movement between the project site and recipient site, health assessments of the resident desert tortoisesshould be conducted; however, no disease sampling via blood samples will be necessary. For monitoring purposes, if fiveor more desert tortoises will be translocated, an equal number of desert tortoises within the recipient site, and an equal number of control desert tortoises should be assigned a unique identifier (provided by USFWS) and be fitted with a transmitter by qualified personnel. If fewer than 5 desert tortoises will be translocated less than 500 m, only the translocateddesert tortoiseswould be monitored.

When the recipient site will be receiving desert tortoises that will be moved greater than500m from the point of collection or there are barriers to impede natural dispersal between the project site and recipient site, health assessments of the resident desert tortoisesshould be conducted and the assessments must include disease testing via blood samples. The activity of the desert tortoise immune system dictates that blood samples be drawn between May 15 and October 31. The activity of the immune system generally corresponds to the active season of the desert tortoise, but desert tortoises are unlikely to be above ground when temperatures exceed 40°C (104°F), making them often unavailable for blood sampling during June through August.

7. Determine if desert tortoises on the project site will be held *in*- or *ex situ*. The translocation plan should identify which of the following interim holding/monitoring arrangements will be used for the desert tortoises on the project site. This step can be conducted concurrently with Step 6 and construction of fencing at the project site under Step 8. Regardless of the option selected, tortoises should be translocated within 18 months of collection.

If 10 or more desert tortoises are expected to be translocated, one of the forms of quarantine should be implemented while a disposition plan is prepared by the proponent and submitted to

the USFWS and State wildlife agencies. Disposition plans should articulate the proposed fate of each desert tortoise (*i.e.*, translocated to recipient site or removed from population due to suspected disease) expected to be translocated and include the complete health assessment for each individual. Desert tortoises should not be moved prior to concurrence by the USFWS with the health assessments and disposition plans.

Either of the following optionsmay be selected regardless of the distance tortoises are being moved:

Option 1: *Ex situ* monitoring – Construction of individual quarantine facilities off-site. Tortoises located during protocol clearance surveys (see Desert Tortoise Field Manual at website above) would be transferred to an off-site quarantine facility. The facility design, animal husbandry plan,and operating protocols should be developed by experienced personnel from an accredited American Zoological Association institution and be approved by USFWS and State wildlife agencies. Facilities should be constructed and managed to prevent tortoises from coming into contact with one another, exclude predators, provide ability for appropriate thermoregulation, and allow for necessary husbandry activities by a caretaker that is certified to conduct health assessments and administer care. If this option is selected, quarantine facilities should be constructed to avoid inadvertently capturing any resident desert tortoises within the enclosure. If suitable USFWS and State wildlife agency-approved facilities exist in the area, the project proponent may inquire with facility managers about temporary use; however, these opportunities are currently extremely limited.

Option 2: *In situ* monitoring – Monitoring desert tortoises on the project site via telemetry. As protocol clearance surveys are conducted, health assessments, including blood draws, assignment of unique identifiers (provided by USFWS), and affixing transmitters should be performed on each tortoise as it is located. Telemetry monitoring would then be conducted a minimum of once per month with more frequent monitoring under certain circumstances. Data to be collected will be standardized for all projects.

8. Construct project fencing, conductprotocol clearance surveys of the project site, and perform complete health assessments.

Component Specific

Perimeter Fence:Fence construction may be doneduring any season; however, any desert tortoiseslocatedduring clearance surveys of the perimeter fence shouldbe treated as translocatees and moved to the recipientsite during the active season(generally between April 1 and May 31 or September 1 and October 15). If clearance of the perimeter fence is conducted outside of the desert tortoise active season, then any desert tortoiseslocatedalong the alignment should be moved out of harm's way but to the inside of the perimeter fence (*i.e.*, onto thepower plant site), be fitted with a transmitter, blocked into an artificial or empty natural burrow and monitored as described below.

Power Plant Site: Clearance surveys, appropriate health assessments,and subsequent translocation should be conducted during the active season.

Linear Facilities (*e.g.*, transmission and buried lines): Clearance surveys may be conducted during any season. Any desert tortoises found during clearance of linear facilities should be moved out of harm's way following clearance and handling procedures outlined in the current FWS Desert Tortoise Field Manual.

General

Any desert tortoisesencountered during clearance of the power plant site or the perimeter fence should be given a health assessmentprior to being moved to the translocation site or quarantine facility, regardless of the distance the desert tortoise is expected to be translocated. Health assessments for desert tortoises being moved greater than 500m include blood tests. During the health assessment, desert tortoises will be assigned a unique identifier (provided by USFWS) and a transmitter will be attached for monitoring purposes. If the desert tortoise is being moved to a quarantine facility it will not be fitted with a transmitter until it leaves the quarantine facility. Modifications to marking procedures may be required for small desert tortoises.

Data collected during clearance surveys should include detailed information about the exact point of collection (UTMs from GPS, description of location, etc.) and will be standardized for all projects. For those desert tortoises that will be monitored *in situ*, these data should be collected again on the day of translocation from the project site. Each desert tortoise will be assigned a unique identifier (to be provided by USFWS), which will allow us to link each individual desert tortoise with data obtained during clearance surveys and subsequent health assessments.

The placement of the desert tortoises following the health assessments will depend on the translocation plan (*i.e.*, holding/monitoring option) approved under the incidental take permit or biological opinion. There are four potential outcomes for each desert tortoise:

a. Translocation on the day of collection if the total number of desert tortoises expected to be translocated is less than 10 (see above for translocation of 10 or more desert tortoises). This option may be used for desert tortoises being moved less than500m from the point of collection to lands contiguous with the project site (*i.e.*, no barriers to natural dispersal). These individuals do require complete health assessments, but do not require disease testing via blood samples.

b. Transfer of healthy desert tortoises to quarantine facility for holding (*ex situ*). Desert tortoises should not be held in the quarantine facilities for greater than 18 months.

c. Remain on-site for *in situ* monitoring until translocation, pending disease testing results andconcurrence with results of complete health assessments (and disposition plan if 10 or more desert tortoises to be translocated). This option may be used for desert tortoises regardless of the distance to the translocation site.

d. Transfer to Desert Tortoise Conservation Center (DTCC) in Las Vegas, Nevada or another agency-approved facility. Transferring desert tortoises to the DTCC or other approved facility is only appropriate for individuals showing clinical signs of infection or have positive blood tests. (See criteria below.)

Health Assessments:Health assessments must be conducted by individuals approved and permitted by the USFWS and State wildlife agencies to conduct such assessments. Individuals should inquire with USFWS about opportunities to receive certification. Because of new health assessment standards and the need for standardized data, certification will not be granted solely on past experience. Training for performing health assessments and drawing blood is currently available at the DTCC on a first come, first served basis. Health assessment training will consist of a 5-day rotation at a cost of approximately $1500, and training for drawing blood will consist of a separate 5-day rotation at a cost of approximately $1800.Depending on one's previous

experience, the opportunity to test out of the respective modules may be available. After an individual has been certified to conduct health assessments and draw blood and has processed desert tortoises for a particular project, a veterinarian shouldverify the findings submitted by that individual to ensure proper placement of the desert tortoises.

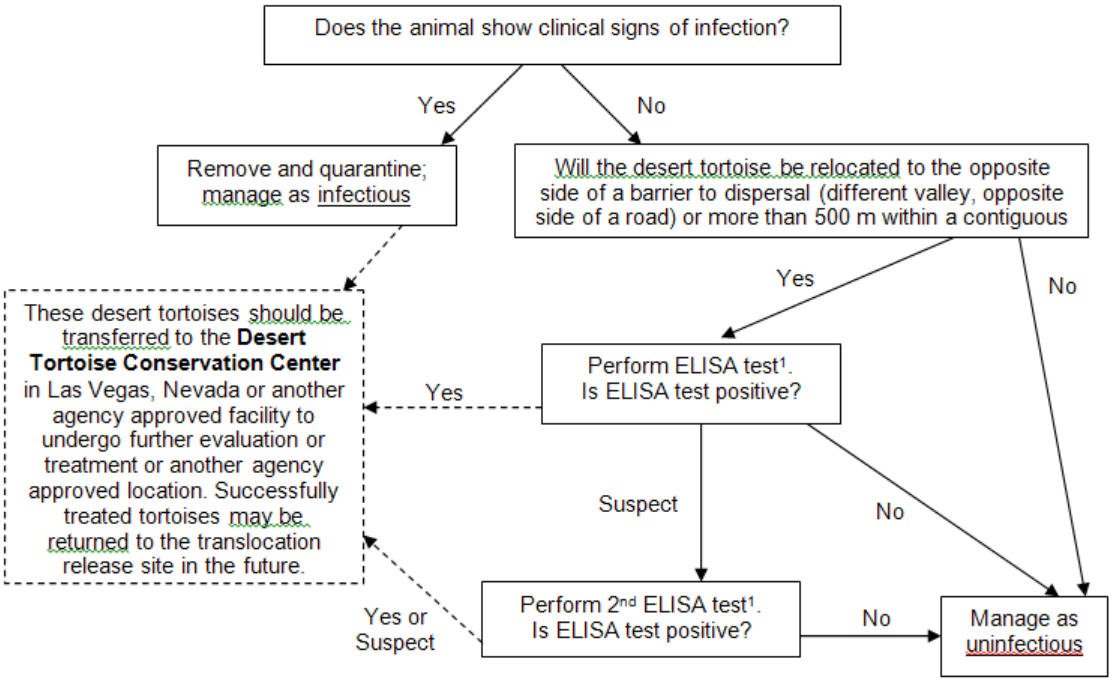
Health assessments will include a physical inspection (*i.e.*, notation of clinical signs of acute disease infection, body mass, and carapace measurements). The need to draw blood fromdesert tortoises within the project area depends on the presence or absence of clinical signs and the distance that desert tortoises will be translocated (see Step 8 and Table 1). See Pre-translocation disease screening decision tree (Figure 1) for specifics.

If a desert tortoise being monitored *in situ* has a positive blood test result, all desert tortoises with a negative blood test result within 500 m of the positive desert tortoise's initial and current locations should be retested in case they came into contact with the unhealthy individual while initial test results were pending. The desert tortoisesshowing clinical signs or test positive for disease will not be eligible for translocation and should be removed from the project site and sent to the DTCC or other agency-approved facility as described below.

9. Concurrence with results of complete health assessments and disposition plans and translocation of desert tortoise following results of disease testing. Once health assessments are complete and disease test results received, the disposition of each individual should be proposed and submitted to the USFWS and the State wildlife agencies for review and concurrence. A disposition plan should be submitted in all cases except when the total number of desert tortoises to be translocated is fewer than 10 **and**thosedesert tortoises are to be moved less than 500 m.

Desert tortoises deemed uninfectious according to the decision tree (*i.e.*, lack of clinical signs and show no antibodies to pathogens) and are of suitable body condition (standards to be provided by USFWS) may be translocated. Translocation should proceed to the selected recipient site(s) in a manner consistent with existing protocols, this guidance, and the project-specific translocation and monitoring plan.Some flexibility may exist for individual projects based on the time of year,local/regional weather patterns, actual weather conditions during the proposed release event, and condition of the donor and recipient sites (*e.g.*, degraded or recently burned). Translocations should occur in spring (April 1 through May 31), but fall (September 1 through October 15) may be considered. In addition, the following conditions should be met for translocation to proceed:

- Releases should occur when temperatures range from 18-30°C (65-85°F) and are not forecasted to exceed 32°C (90°F) within 3 hours of release or 35° (95°F) within 1 week of release. Additionally, forecasted daily low temperatures should not be cooler than 10° C (50°F) for one week post-release. Temperature thresholds for translocation differ from those for handling resident and control desert tortoises because translocated desert tortoises spend more time aboveground subsequent to release as they habituate to unfamiliar surroundings, increasing their susceptibility to stress factors such as temperature extremes.
- Release points for desert tortoises should be pre-selected during visits to the translocation site (configuration of release points is project-specific) and should be at least 2.5 km from any documented seropositive or clinically ill (showing outward signs of disease) resident desert tortoises.



[1]ELISA tests, as developed by the University of Florida, must be conducted for both *Mycoplasma agassizii* and *Mycoplasma testudineum*.

Figure 1. Pre-translocation decision tree.

- Desert tortoises should be transported to their release sites in clean, ventilated protective containers. If re-used, these containers must be disinfected using 10 percenthousehold bleach or other solution approved by USFWS and the State wildlife agency before being used for another desert tortoise.
- Within 12 hours before release, all desert tortoises to be translocated should be hydrated according to existing protocols.
- Desert tortoises should be released at unoccupied shelter sites. Shelters include unoccupied soil burrows, spaces within rock outcrops, caliche caves, and the shade of shrubs.

Desert tortoises determined to be infectious or unhealthy should be sent to the DTCCor other agency-approved facility where they will undergo further assessment, treatment, and/or necropsy; some desert tortoises will be rehabilitated and potentially be eligible for subsequent release.Coordination with the USFWS, State wildlife agencies, and the DTCC should be initiated when clearance surveys commence to facilitate prompt transport of unhealthy desert tortoises, as necessary. The agencies and DTCC staff should be notified of the number of desert tortoises

estimated to be removed from the project site to allow for advanced preparation at the DTCC. Project proponents will be charged a flat fee of $9,000 for each desert tortoise sent to the DTCC commensurate with the cost to provide housing, care, treatment, and other services for 5 years ($3,000 for year 1, $1,500 for years 2to 5). No additional funds will be requested from project proponents for desert tortoises remaining at the center after5 years.

10. Implement post-translocation monitoring (5-yr minimum) and adaptive management to evaluate effectiveness of translocation as a take minimization measure. For projects that require translocation of five or more desert tortoises, monitoring will include an equal number of translocateddesert tortoises, desert tortoises that are resident at recipient sites, and desert tortoises at control sites. For example, if six desert tortoises are to be translocated, six resident, and six control desert tortoises should also be monitored at even sex ratios (regardless of whether or not the group of translocatees has an even sex ratio), if possible. In situations where fewer resident desert tortoises exist at the recipient site than translocatees being added (likely in targeted depleted areas), all residents should be monitored. For projects that expect to translocate fewer than fivedesert tortoises, monitoring will include translocatees only.

Frequency of Monitoring: Monitoring refers to pinpointing the exact location of the desert tortoise and attempting to view it without disturbance unless entrapment or a scheduled body condition assessment requires handling.

Desert tortoises confined to an artificial or empty burrow during perimeter fence construction should be monitored as follows:

- Once a day during first week;
- once a week for the following three weeks; then
- twice per month until the clearance survey is conducted.

Translocateddesert tortoises should be monitored as follows:

- Once within 24 hours of release;and
- a minimum of twice weekly for the first two weeks after release; and
- a minimum of once a week from March through early November for the 5-year monitoring period; and
- once every other week from November through February starting after the third week of release and for the duration of the 5-year monitoring period.

Resident and control desert tortoises should be monitored for the 5-year monitoring period as follows:

- A minimum of once a week from March through early November; and
- A minimum of once every other week from November through February.

Assessments of condition (*i.e.*, measurements of body mass and carapace, health assessment, calculation of body condition) should be conducted during each year of monitoring; one assessment prior to and one assessment subsequent to over-wintering. Any health problems observed (*e.g.*, rapid declines in body condition, perceived outbreaks of disease, mortality events) should be reported to the USFWS and State wildlife agency such that appropriate actions can be taken in a timely manner. Mortalities should be investigated as thoroughly as possible.

Information on health concerns and mortalities, including desert tortoise unique identifier, location, and cause of death (if determined) should be provided to USFWS and State wildlife agency upon discovery (verbally within 48 hours or via email within 5 business days). Fresh carcasses should be submitted for necropsy (details to be provided during project planning and coordination with USFWS) and the cost covered by the proponent.

In addition to monitoring the desert tortoises, we recommend that vegetation transects at representative sampling locations within the recipient site be repeated annually to capture potential changes in habitat characteristics. At a minimum, monitoring of the annual species component is recommended to identify changes in forage diversity and availability. The USFWS will provide additional guidance to project proponents on appropriate methods of vegetation monitoring and sampling during the planning process.

Explicit triggers for implementation of adaptive management will be project specific and developed through coordination with USFWS and State wildlife agencies, as appropriate.

11. Compile and synthesize data throughout duration of translocation. Findings and recommendations will be submitted to appropriate wildlife and/or permitting agencies. The USFWS will provide standardized data fields and database format for use by project proponents; reporting requirements will be determined during the planning process with the appropriate land management and regulatory agencies and incorporated into associated permits and/or biological opinions.

Upon conclusion of the 5-year monitoring period, health assessments should be performed on all remaining monitored desert tortoises and transmitters should remain attached until the USFWS and State wildlife agencies have determined whether or not further action is warranted at the site.

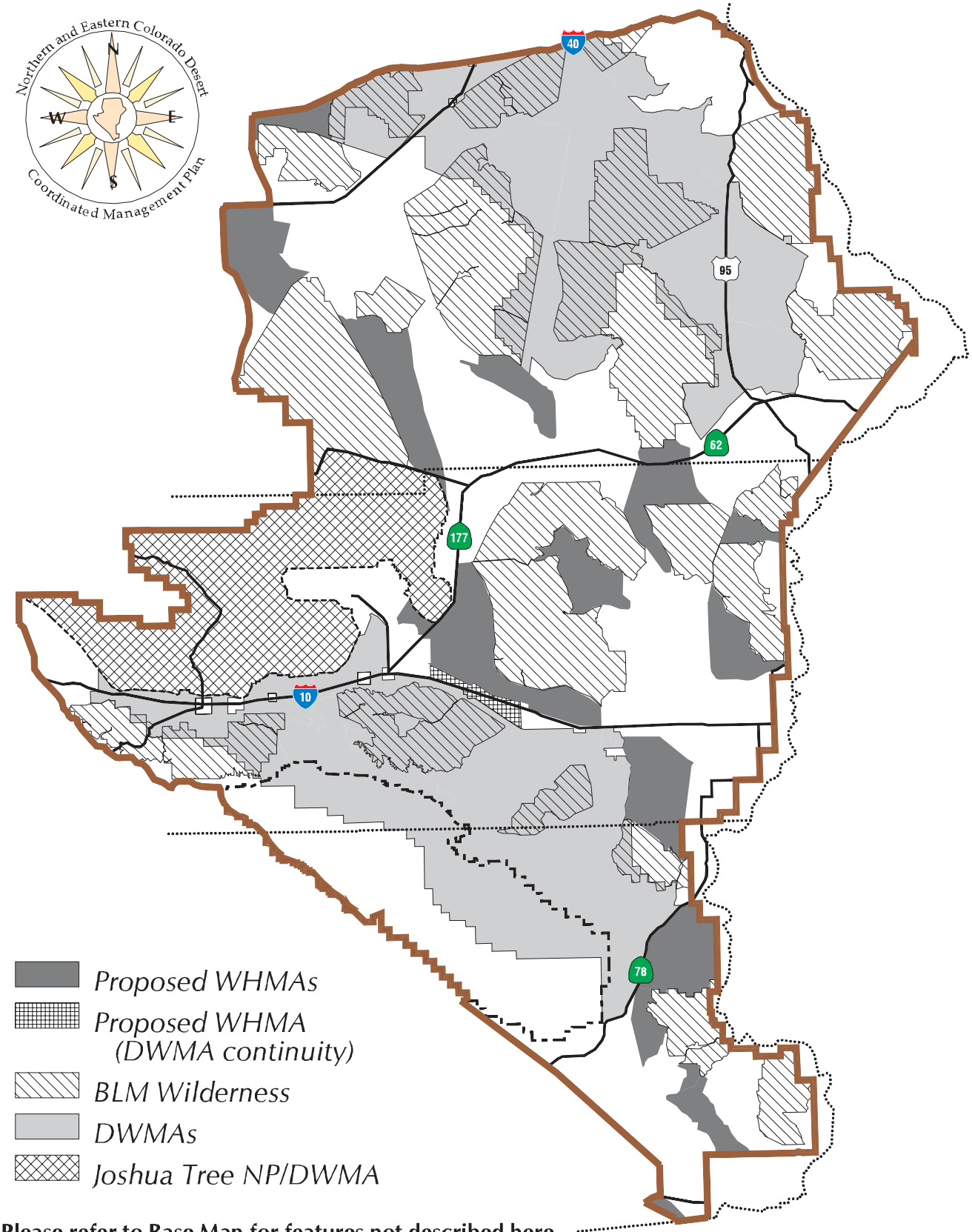
Literature Cited

Desert Tortoise Recovery Office. In prep. Translocation of Desert Tortoises (Mojave Population) from Project Sites: A Technical Paper. Prepared in support of the USFWS's desert tortoise translocation guidance. Reno, Nevada.

Table 1. Desert tortoise translocation components at a glance based on the number of desert tortoises expected to be translocated and the distance they will be moved.If the number of desert tortoises to be translocated is 10 or more, regardless of the distance they will be moved, the desert tortoises should be held and monitored on- or off-site while a disposition plan is prepared and approved by USFWS.

	# of dt<5; moving < 500m	# of dt<5; moving > 500m	# of dt≥ 5; moving < 500m	# of dt≥ 5; moving >500m
Translocatees: health assessment without blood test	X		X	
Translocatees: health assessment with blood test		X		X
Recipient site required	X	X	X	X
Recipient site density surveys required	X	X	X	X
Recipient desert tortoises:health assessment without blood test	X		X	
Recipient desert tortoises:health assessment with blood test		X		X
Control site required			X	X
Control desert tortoises: health assessment with blood test			X	X
Monitoring of translocatees	X	X	X	X
Monitoring of residents			X	X
Monitoring of controls			X	X

Proposed Plan
Multi-Species WHMAs



Please refer to Base Map for features not described here

June 5, 2002

Map 2-21

Scale 1 : 1,120,000

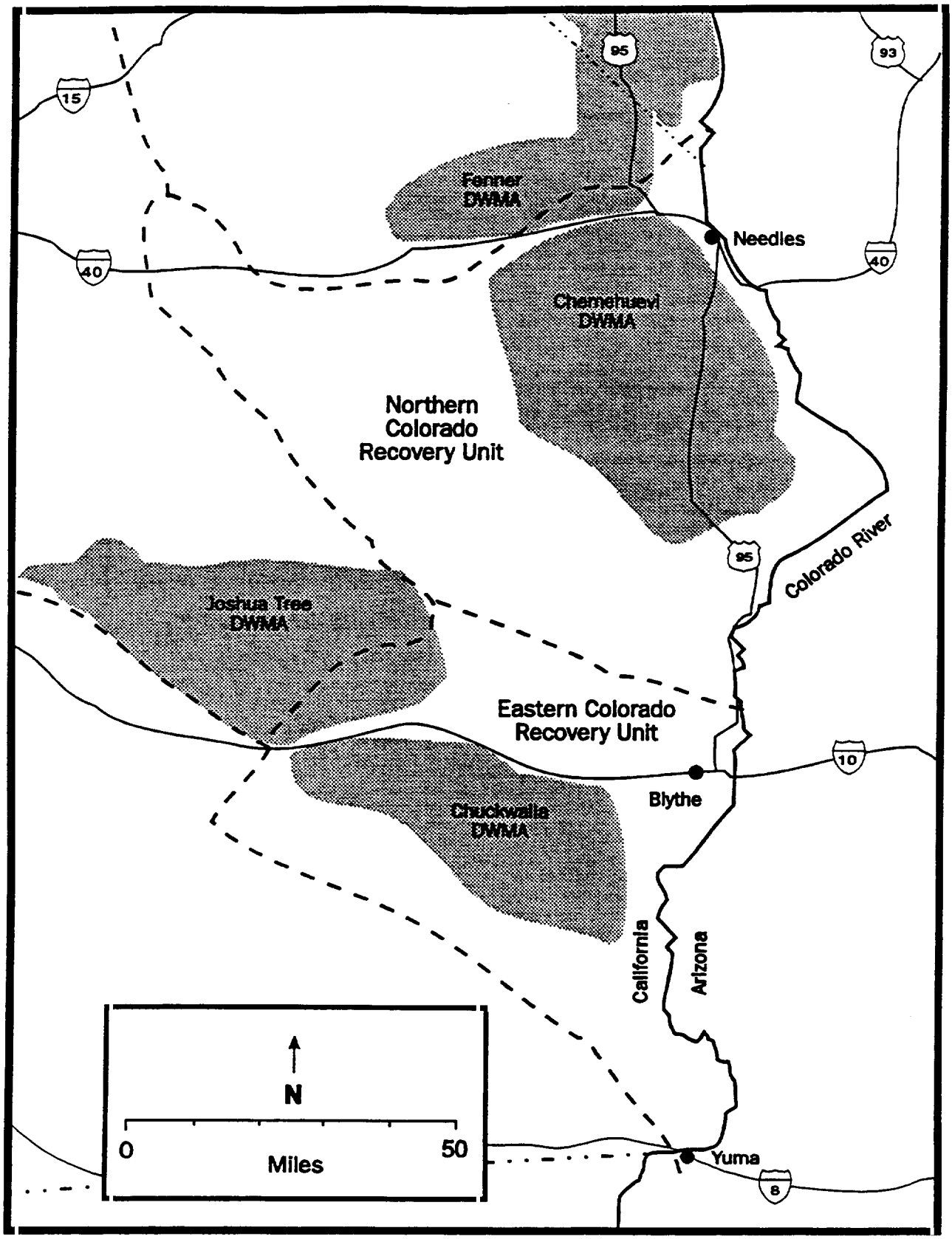


Figure 7. Proposed DWMAs in the northern Colorado and eastern Colorado recovery units.

Chelonian Conservation and Biology, 2007, 6(2): 229–251
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A Genetic Assessment of the Recovery Units for the Mojave Population of the Desert Tortoise, *Gopherus agassizii*

Robert W. Murphy[1], Kristin H. Berry[2], Taylor Edwards[3], and Ann M. McLuckie[4]

[1]*Royal Ontario Museum, 100 Queen's Park, Toronto, Ontario M5S 2C6 Canada [drbob@zoo.utoronto.ca];*
[2]*US Geological Survey, Western Ecological Research Center, 22835 Calle San Juan de Los Lagos, Moreno Valley, California 92553-9046 USA [kristin_berry@usgs.gov];*
[3]*University of Arizona, Arizona Research Laboratories, Genomic Analysis and Technology Core, 246b Biological Sciences West, 1041 E. Lowell, Tucson, Arizona 85721 USA [taylore@u.arizona.edu];*
[4]*Washington County Field Office, Utah Division of Wildlife Resources, 344 E Sunland Drive no. 8, St. George, Utah 84790 USA [annmcluckie@utah.gov]*

Abstract. – **In the 1994 Recovery Plan for the Mojave population of the desert tortoise, *Gopherus agassizii*, the US Fish and Wildlife Service established 6 recovery units by using the best available data on habitat use, behavior, morphology, and genetics. To further assess the validity of the recovery units, we analyzed genetic data by using mitochondrial deoxyribonucleic acid (mtDNA) sequences and nuclear DNA microsatellites. In total, 125 desert tortoises were sampled for mtDNA and 628 for microsatellites from 31 study sites, representing all recovery units and desert regions throughout the Mojave Desert in California and Utah, and the Colorado Desert of California. The mtDNA revealed a great divergence between the Mojave populations west of the Colorado River and those occurring east of the river in the Sonoran Desert of Arizona. Some divergence also occurred between northern and southern populations within the Mojave population. The microsatellites indicated a low frequency of private alleles and a significant correlation between genetic and geographic distance among 31 sample sites, which was consistent with an isolation-by-distance population structure. Regional genetic differentiation was complementary to the recovery units in the Recovery Plan. Most allelic frequencies in the recovery units differed. An assignment test correctly placed most individuals to their recovery unit of origin. Of the 6 recovery units, the Northeastern and the Upper Virgin River units showed the greatest differentiation; these units may have been relatively more isolated than other areas and should be managed accordingly. The Western Mojave Recovery Unit, by using the new genetic data, was redefined along regional boundaries into the Western Mojave, Central Mojave, and Southern Mojave recovery units. Large-scale translocations of tortoises and habitat disturbance throughout the 20th century may have contributed to the observed patterns of regional similarity.**

Key Words. – **Reptilia; Testudines; Testudinidae; *Gopherus agassizii*; tortoise; conservation genetics; distinctive population segment; evolutionary significant unit; management units; microsatellites; mitochondrial DNA; Mojave Desert; USA**

The desert tortoise (*Gopherus agassizii*) is a widespread species (or possible species complex) occurring in the southwestern United States and northwestern Mexico (Fritts and Jennings 1994; Berry et al. 2002; Stebbins 2003). The US Fish and Wildlife Service (USFWS) federally listed the species as threatened under the Endangered Species Act, as amended, in the northern one third of its geographic range, specifically, populations living north and west of the Colorado River in the Mojave and Colorado deserts (USFWS 1990; Fig. 1). The listing occurred primarily because of population declines and habitat loss and deterioration, which were attributed to human activities. In recognition of the distinctiveness of the threatened populations, the USFWS developed the *Desert Tortoise (Mojave Population) Recovery Plan* (referred to herein as *Recovery Plan*) (USFWS 1994) and designated 26,087 km^2 of critical habitat (Berry 1997). About 83% of the critical habitat is on land managed by government agencies.

The federal listing of the desert tortoise as a threatened species brought about a redirection of government efforts to recover the species within its 4 southwestern states (California, Arizona, Nevada, and Utah). Several government agencies prepared new long-term management plans or amended older land-use plans to support recovery efforts (Berry 1997), a process that required more than 16 years. The extent of landscape affected by these efforts was significant and included parts of the Mojave Desert and the Colorado Desert (also called western Sonoran Desert). For convenience, the USFWS termed the populations within critical habitat as the "Mojave" population, when in fact they occur in both the Mojave and Colorado deserts. Herein, we follow this terminology. For populations in the Sonoran Desert of Arizona, we use "Sonoran" populations.

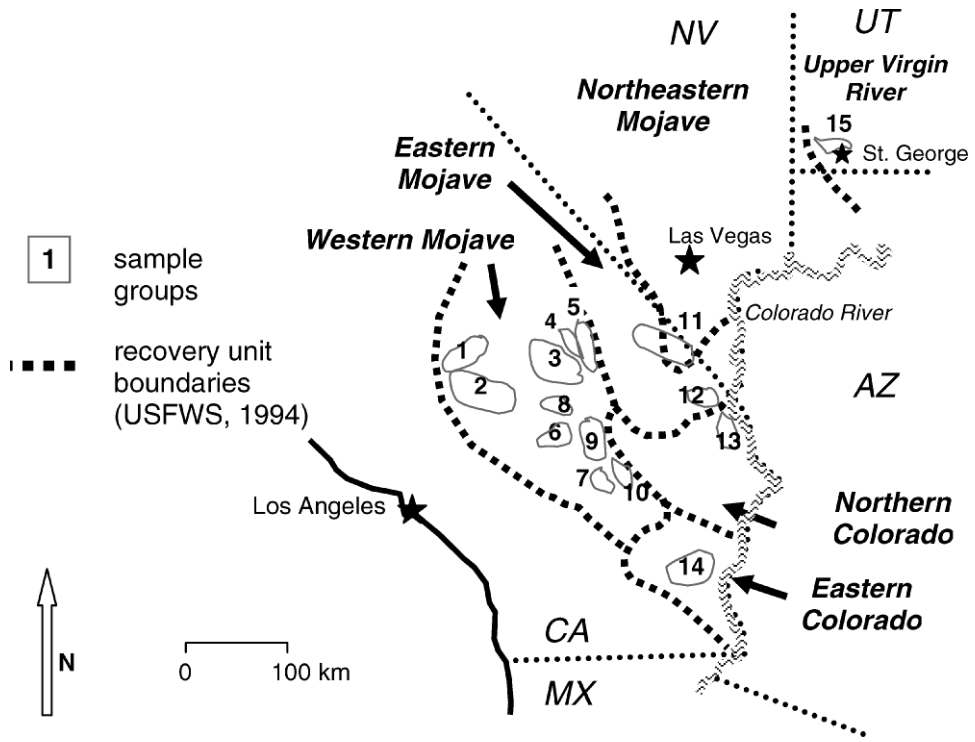

Figure 1. Sample groups and recovery unit boundaries for *Gopherus agassizii* as described in the *Desert Tortoise (Mojave Population) Recovery Plan* (USFWS 1994) and sample sites for this study. Because of their geographic proximity, 3 tortoises from the Eastern Mojave Recovery Unit were combined with 57 tortoises from the Northeastern Mojave Recovery Unit to form sample group 11.

Desert tortoises exhibit substantial differences in morphology (Weinstein and Berry 1987; Germano 1993), physiology (Turner et al. 1986; Wallis et al. 1999; Averill-Murray 2002; Averill-Murray et al. 2002a, 2002b; McLuckie and Fridell 2002), behavior (e.g., Woodbury and Hardy 1948; Burge 1977; Averill-Murray et al. 2002b; Jennings 2002), and genetics (Lamb et al. 1989; Lamb and Lydeard 1994; McLuckie et al. 1999; Lamb and McLuckie 2002) throughout the geographic range in the United States. This variation occurs within and between the Mojave and Sonoran populations.

The authors of the *Recovery Plan* recommended protection of 6 evolutionarily significant units (ESUs) or distinct population segments (DPSs) in 6 "recovery units" (Ryder 1986; Waples 1991, 1998; US Department of the Interior and US Department of Commerce 1996). They noted that the ESUs (or DPSs) consisted of "populations or groups of populations that show significant differentiation in genetics, morphology, ecology or behavior . . . and thus are important components of the evolutionary legacy of *Gopherus agassizii*" (USFWS 1994). They stated that the conservation of all ESUs would help to ensure that "the dynamic process of evolution [in this species] will not be unduly constrained in the future [Waples 1991]" (USFWS 1994). It is important to note that the authors used the phrases ESUs, DPSs, and recovery units synonymously, and their intent was to draw on multiple criteria to delineate units (after Waples 1991, and similar to Crandall et al. 2000). The USFWS also recommended that concepts in the *Recovery Plan* be subjected to hypothesis-testing. In the case of genetics, the limited available mitochondrial deoxyribonucleic acid (mtDNA) data suggested that *G. agassizii* might be composed of more than 1 species, with the Colorado River acting as a boundary in the northern part of the geographic range (Lamb et al. 1989; summarized in Berry et al. 2002).

Since the *Recovery Plan* (USFWS 1994) was published, the fields of population and conservation genetics have advanced rapidly. Numerous new, powerful techniques are now available for processing, statistically analyzing, and interpreting genetic samples (e.g., DeSalle and Amato 2004; Pearse and Crandall 2004; Manel et al. 2005; Allendorf and Luikart 2007). In 1996, the federal government further clarified the Endangered Species policy on DPSs for vertebrates (US Department of the Interior and US Department of Commerce 1996). The academic dialog on the definitions and applicabilities of ESUs, DPSs, and other related concepts, such as management units (MUs), Canadian designatable units (DUs), and adaptive evolutionary conservation has continued to be rigorous and brisk (Crandall et al. 2000; Fraser and Bernatchez 2001; Pearman 2001; Moritz 2002; Green 2005). However, distinct infraspecific populations of American vertebrates, except for salmonid fishes, can currently only receive legal protection as DPSs, not as ESUs.

A factor complicating the genetic study of desert tortoise populations has been human-mediated translocation. The tortoise has received much well-intended attention by governmental agencies and concerned citizens

since the 1930s (California Code of Regulations 2007). Thousands of tortoises have been taken into captivity and then released. Still others have been translocated from one area to another in the desert. Commercial harvesting and interstate transportation have been significant.

Our objectives are to contribute to recovery efforts for this species by: 1) characterizing genetic differences in the Mojave populations to determine whether the existing 6 recovery units are genetically distinguishable and, if so, to what extent; 2) evaluating the potential effects of numerous releases and translocations of tortoises on genetic structure; and 3) placing the genetic data in the context of ecological and behavioral differences in desert tortoises to support the conservation of ecological and evolutionary processes.

METHODS

Sample Collection

We salvaged blood from desert tortoises used in research projects on health, disease, and physiology, and through collaboration with other scientists (Henen et al. 1997; Brown et al. 1999; Christopher et al. 1999, 2003; Edwards 2003). Desert tortoises were captured by hand in the field by following federal and state protocols (Averill-Murray 2000; Berry and Christopher 2001). Samples were collected from tortoises ($n = 628$) at 31 study sites that occur within the geographic range where the tortoise is federally listed (USFWS 1990) (Table 1; Fig. 1). We did not include sites from Nevada or the Beaver Dam Slope, Utah. Study sites were in remote areas as well as < 2 km from towns or human habitation. We also obtained mtDNA sequences from 4 *G. agassizii* from the Sonoran Desert of Arizona (Edwards et al. 2003), 1 sample of the bolson tortoise (*Gopherus flavomarginatus*) from a private collection, and 1 sample of the Texas tortoise (*Gopherus berlandieri*) from the Department of Animal Care and Technologies at Arizona State University, Tempe (J. Badman).

About 1 ml whole blood was collected via brachial, jugular, or subcarapacial venipuncture, and the samples were stored on ice or dry ice in (ethylenediamine tetraacetic acid [EDTA]), lithium heparin, or 95% ethanol. Most samples (from health and disease studies) were centrifuged first, the plasma was removed, and the red blood cells were retained and frozen for DNA extraction.

Molecular Techniques

Molecular procedures were conducted at the Genomic Analysis and Technology Core, University of Arizona. Genomic DNA was isolated from blood by overnight lysis with proteinase K at 55°C, followed by a phenol/chloroform extraction and isopropanol/sodium acetate precipitation (Goldberg et al. 2003). The DNA was resuspended in low TE (10 mM Tris-pH 8.0, 0.1 mM EDTA) and diluted to a 5 ng/μL working stock for polymerase chain reaction (PCR) amplifications.

MtDNA Sequencing. — We amplified an ca.1500–base-pair (bp) portion of the nicotinamide adenine dinucleotide dehydrogenase subunit (ND)3, arginine transfer RNA (tRNA) ND4L, and part of the ND4 genes by using primers Nap2 and New Gly (Arévalo et al. 1994; Britten et al. 1997; Edwards 2003). PCR followed Edwards (2003), and the PCR products were purified by using the QIAquick PCR purification kit (Qiagen, Valencia, CA) and were sequenced on an ABI Prism 3700 DNA Analyzer (PE Biosystems, Foster, CA). Internal primers were designed by using Oligo Primer Analysis Software 6.68 (Molecular Biology Insights, Inc, Cascade, CO): Nap2IN 5'AGGCGGTCAATAATGC-TAATC3' and NewGIN 5'TAATAAAACCAGACAAT-GAAAAAC3'. These primers amplified an 1109-bp portion of ND3/ND4, which was aligned and evaluated by using Sequence Navigator 1.0.1 (Applied Biosystems, Inc, Foster, CA).

Nuclear DNA Assessment. — Data gathering was carried out on an ABI Prism 3730 DNA Analyzer (PE Biosystems). All samples were tested for 16 microsatellite loci (Table 2). The loci were PCR amplified in 6 separate multiplex reactions by using 5' fluorescently labeled forward primers. We sequenced selected products for all loci to verify repeat motifs. Repeat motifs were identified by using Sequence Navigator 1.0.1 (Applied Biosystems, Inc). Reliably scored, variable loci were used for analysis.

Analysis

Grouping of Samples. — Sample sizes from each of the 31 study sites ranged from 3 to 74 (Table 1). Study sites were assigned to 1 of 15 sample groups based on location, proximity to nearby sites (≤ 60 km), potential topographic or geographic barriers to movement of tortoises, region of the desert, recovery unit as described in the *Recovery Plan* (Fig. 1), and the need to maintain a minimum sample size for statistical analyses. Thus, the 15 sample groups contained 18–83 tortoises (Table 1). Sample group 11 combined individuals from Ivanpah, California ($n = 57$), which belong to the Northeastern Mojave Recovery Unit, with 3 tortoises from Shadow Valley in the Eastern Mojave Recovery Unit owing to close geographic proximity of the localities. We assigned groups to regions of the Mojave and Colorado deserts by using boundaries similar to those described in Rowlands et al. (1982), and the boundary between the Mojave and Colorado deserts as described in Jaeger (1957), Benson and Darrow (1981), Rowlands et al. (1982), and Turner et al. (1995). For boundaries delineating the northern and eastern regions within the Colorado Desert, we followed the *Recovery Plan* (USFWS 1994; Rowlands 1995a, 1995b).

MtDNA. — We selected 125 tortoises representing all recovery units, including 47 samples from the Northeast-

Table 1. Desert tortoise study sites and sample groupings representing 8 regions for the Mojave population.

Desert region/recovery unit	Study site	No. samples	Group	No. samples in group
Western Mojave	Desert Tortoise Research Natural Area	58	1	62
	Fremont-Valley	4	1	
	Hinkley	12	2	83
	Kramer	3	2	
	Edwards Air Force Base	57	2	
	Fremont-Kramer	11	2	
"Central Mojave"	Superior-Cronese	10	3	19
	Fort Irwin (Goldstone)	9	3	
	Fort Irwin (Tiefort)	31	4	31
	Fort Irwin (Soda Mtns.)	33	5	47
	Fort Irwin (Eastgate 2)	14	5	
"Southern Mojave"	Lucerne Valley	12	6	26
	Ord-Rodman	14	6	
	MCAGCC[a] (Emerson)	9	7	71
	MCAGCC (Sand Hill)	62	7	
	Daggett	74	8	74
	MCAGCC (Lavic Lake)	8	9	27
	MCAGCC (Maumee Mine)	7	9	
	MCAGCC (Sunshine Peak)	12	9	
	MCAGCC (Bullion)	16	10	19
	MCAGCC (Lava)	3	10	
Northeastern Mojave	Ivanpah	34	11	60
	Ivanpah (site 14)	23	11	
	Shadow Valley[b]	3	11	
Eastern Mojave	Fenner	4	12	31
	Goffs	27	12	
Northern Colorado	Chemhuevi	7	13	18
	Upper Ward Valley	11	13	
Eastern Colorado	Chuckwalla	18	14	37
	Chocolate Mtns.	19	14	
Upper Virgin River	near St. George, UT	23	15	23

[a] MCAGCC = Marine Corps Air Ground Combat Center.
[b] Population occurring in the Eastern Mojave Recovery Unit assigned to the Northeastern Mojave sample group for purposes of data analysis owing to geographic proximity.

Table 2. Observed microsatellite motifs in Mojave desert tortoises, *Gopherus agassizii*, compared with that of the originally described species or population.

Locus	Species originally described	Original repeat motif	Observed motif in Mojave population	Range of Mojave alleles	Range of Sonoran alleles
Edwards et al. 2003					
Goag3	*G. agassizii* (Sonoran)	$(CAA)_6$	$(CAA)_6$	6–7	6–9
Goag4	*G. agassizii* (Sonoran)	$(CAA)_{24}$	$CAA)_{24}$	12–32	7–30
Goag5	*G. agassizii* (Sonoran)	$(GAT)_8$	$GACGAA(GAT)_2GACGAA$	null	6–38
Goag6	*G. agassizii* (Sonoran)	$(TC)_8(AC)_{11}$	$(TC)_8(AC)_{11}$	17–-67	15–52
Goag7	*G. agassizii* (Sonoran)	$(AC)_3(GC)_5(AC)_{11}$	$(AC)_8(AT)_2GC(AC)_3(GC)_3(AC)_9$	13–28	12–28
Goag32	*G. agassizii* (Sonoran)	$(AC)_6$	$(AC)_6$	6	5–6
Schwartz et al. 2003					
GP26	*Gopherus polyphemus*	$(GT)_{12}$	$(GT)_7$	7	6–9
GP55	*G. polyphemus*	$(GT)_9$	$(GT)_7$	7–30	7–34
GP102	*G. polyphemus*	$(GT)_5(CT)_{13}(CA)_5$	$(TC)_2(TG)_2CG$ [$(TG)_8(TC)_{14}$][a]	19–42	19–36
GP15	*G. polyphemus*	$(GA)_{15}(GT)_8$	$(GA)_{14}(GT)_{20}$	13–52	13–56
GP19	*G. polyphemus*	$(GT)_9/(GT)_3(GA)_6$	Allele 1; $(GT)_3/(GT)_2GAAA(GA)_4$ Allele 2; $(GT)_7ATGTATGT/(GT)_2GAAA(GA)_5$	11 and 21	6, 11, and 21
GP30	*G. polyphemus*	$(GT)_{13}$	$(GT)_5(CT)(GT)_4$	10–17	5–29
GP81	*G. polyphemus*	$(GT)_{11}(GA)_{10}$	$(GT)_9GACA(GA)_8$	16–28	18–22
GP61	*G. polyphemus*	$(GT)_{12}$	$(GT)_4AT(GT)_6$ & $(GT)_{16}$	11–38	9–43
GP96	*G. polyphemus*	$(GA)_{11}$	$(GA)_7$	7	7
FitzSimmons et al. 1995					
Cm58	*Chelonia mydas*	$(CA)_{13}$	$(TA)_5(GA)_3GC(GT)_3$	12	12–13

[a] Complex repeat; unable to obtain entire sequence.

ern Recovery Unit, and sequenced their mtDNA for a total evidence analysis (Kluge 1989; Ernisse and Kluge 1993) of unique haplotypes only. Unweighted maximum parsimony analyses were performed on potentially informative characters by using PAUP* 4.0b10 (Swofford 2002). Most parsimonious trees were obtained by using the heuristic tree search algorithm with random addition of individuals, 10,000 replicates while retaining minimal trees only and holding 10 trees at each replicate, tree bisection-reconnection branch swapping with the steepest descent, and collapsed zero-length branches. All multistate characters were evaluated as nonadditive (unordered). Nodal consistency was assessed by using nonparametric bootstrap proportions (Felsenstein 1985) and decay analysis (Bremer 1994) performed in PAUP*. Relative nodal support was assessed by using bootstrapping with 10,000 random pseudoreplicates of the data, with each pseudoreplicate being replicated twice.

Bayesian inference was also used to hypothesize matriarchal history (Huelsenbeck and Ronquist 2001; Buckley et al. 2002; Nylander et al. 2004; Ronquist 2004). MrModeltest 2.2 (Nylander 2004) was used to select the best evolutionary model based on the Akaike Information Criterion (Akaike 1974, 1979). Hierarchical likelihood ratio tests (Goldman 1993) compared log-likelihood scores of 56 models. Bayesian inference, conducted by using MRBAYES 3.1.2 (Huelsenbeck and Ronquist 2001), started with random trees. Six Markov chains were used, and the data set was run for 3×10^6 generations. Trees were sampled every 100 generations. Two independent analyses with different starting trees were run and the fluctuating values of likelihood were graphically monitored (Huelsenbeck and Bollback 2001). Log-likelihood scores of sample points were plotted against generation time to establish stationarity (Huelsenbeck and Ronquist 2001). The analysis was a priori required to achieve a split frequency standard deviation of ≤ 0.005. After discarding 25% of the sampled trees as burn-in, the remaining trees were used to generate a 50% majority rule consensus tree.

Nuclear DNA. — We used several methods of analyses to assess gene flow and population differentiation. Each of the methods had different assumptions and relied on different properties of the data, as noted below.

Population Structure. — We used 1) traditional techniques that a priori defined sample groups and 2) an a posteriori genotypic clustering method to analyze population structure. Individuals for which more than 3 loci did not amplify were discarded. Allelic frequency distributions for unique (study site or region restricted) and private alleles (> 5% in a sample group or region) were examined. Loci that exhibited more than 7 alleles were examined by using the log-likelihood-based (G-based) exact test (Goudet et al. 1996) in GENEPOP 3.1 (Raymond and Rousset 1995). A triangular contingency table and a modified version of the Markov-chain random walk algorithm (Guo and Thompson 1992) were used in ARLEQUIN 2.0 (Schneider et al. 2000) to detect significant departures from the Hardy-Weinberg equilibrium (H-W). The multiple tests were not Bonferroni corrected because we looked for trends only and not a precise application of statistical tests. The trends would have remained with a Bonferroni correction but the levels of significance (p-values) would have been raised, possibly to the extent of no significance. Default parameters in GENEPOP and ARLEQUIN were used for all Markov-chain tests and permutations.

Linkage equilibrium is assumed by some statistical tests and, thus, was necessary to confirm. GENEPOP tested for linkage disequilibrium (nonrandom association between loci) among all pairs of loci in the entire sample and within each group by using the method of Garnier-Gere and Dillmann (1992).

Population genetic structure was assessed under nonequilibrium conditions (Pearse and Crandall 2004; Manel et al. 2005). We used STRUCTURE 2.1 (Pritchard et al. 2000) to a priori define cohesive genetic units. Because it does not provide a good measure of genetic structuring in populations that exhibit nonlinear patterns of isolation-by-distance (IBD; Kimura and Weiss 1964; Pritchard et al. 2000), as do Mojave desert tortoises, STRUCTURE was used as a guideline only. An extension to the program by Falush et al. (2003) accounts for correlations between linked loci that arise in admixed populations. We evaluated the 15 sample groups (K populations) with 4 simulations of 500,000 iterations for each K by using the default parameters for an admixture model with a prior mean Φ_{ST} (F_{ST} sensu Weir and Cockerham 1984) of 0.06 (0.05 SD), based on the mean generated from our data set. (We initially also tried the analysis with a lower number of runs by using prior mean Φ_{ST} of 0.01, without a noticeable difference in the outcome.) The best model had the smallest value of K and the largest likelihood values.

To reduce the strongest effects of multilinear IBD, we performed an analysis on the Western Mojave Recovery Unit but first removed the northern- and southernmost samples. The analysis included sample groups 1–10 and used 1,000,000 iterations with a prior mean of Φ_{ST} at 0.01.

Population differentiation was also assessed by using WHICHRUN 4.1 (Banks and Eichert 2000), which calculates the likelihood of a given individual originating from either of 2 or more candidate populations. If the groups identified by STRUCTURE and/or the 6 units hypothesized in the Recovery Plan were distinct and not interconnected by frequent gene flow, then WHICHRUN should assign an individual to its source population with a high likelihood score and assign it to other populations with low scores. Stringency for population allocation used a selection criterion of the log of the odds ratio (LOD) for the 2 most likely source populations. The chance of error is equal to the inverse of this ratio; assignments with a LOD of at least 2 had a ≤ 0.01 chance of error.

Traditional equilibrium-based F-statistics, using analysis of molecular variance (AMOVA) in GENEPOP, were also employed to infer population structure. Inbreeding coefficients (Φ_{IS}; F_{IS} sensu Weir and Cockerham 1984) were calculated for each locus in each sample group. Genetic distances based on pairwise Φ_{ST} were calculated among groups and individuals by using GENEPOP and were visually assessed by producing a multidimensional monotonic scaling plot (MDS) that used the program NTSYS (Exeter Software, NTSYS pc 2.1, Setauket, NY). Goodness of fit was measured by using the Stress test (Kruskal and Wish 1978). Mantel tests obtained from NTSYS assessed correlations between genetic and geographic distances among sample groups. The Φ_{ST} values estimated population structure and gene flow by assuming mutation-drift or migration-drift equilibrium with symmetric migration in both directions for all pairwise combinations of populations. The Φ_{ST} values also assumed an island model that may not be met in desert tortoises, especially because they have experienced recent demographic declines (see Whitlock and McCauley 1999).

Demographic History. — Two very different models assessed historical changes in population density. First, BOTTLENECK (Piry et al. 1999) was used to test for evidence of historical changes in effective population sizes and deviations from equilibrium conditions for each of the sample groups, regions, and the entire population. Populations with recent reductions in effective population size should show an excess of heterozygosity (Cornuet and Luikart 1996; Spencer et al. 2000). Significance of the observed deviations, assuming the infinite alleles model, was determined by the Wilcoxon test as well as the Sign test method of Piry et al. (1999). Second, the M-ratio test of Garza and Williamson (2001) was used to investigate changes in population density and to evaluate bottlenecking, where M is the ratio of the total number of alleles (k) to the overall range in allele size (r). When rare alleles are lost during a population bottleneck, the number of allele size classes is reduced to a greater extent than the range in allele size. Value M is reduced in populations known to have declined in size. In total, 20 populations had the required number of individuals for applying this test. Bottlenecking was assumed to have occurred if M was above the critical value M_C (Garza and Williamson 2001). Congruent findings from the 2 tests would suggest that the results were not biased for any single method or set of assumptions.

Human-Mediated Translocations. — We compiled published and unpublished data and interviewed biologists in state and federal wildlife and land management agencies, then mapped localities of releases or escapes of captive tortoises and translocations of wild tortoises. The results of WHICHRUN assessed the source of an individual tortoise and assignments or misassignments to specific populations. BOTTLENECK, G-based exact tests in GENEPOP, and estimates of inbreeding values (Φ_{IS}) provided information on population trends. Significant deviations from H-W, estimates of recent gene flow and distributions of haplotypes from previously described analyses also provided valuable information.

RESULTS

MtDNA Evaluation. — Estimations of maternal history and population structure were based on *G. agassizii* from the Mojave population and the outgroup taxa (Table 3). All sequences were deposited in GenBank (Accession no. DQ649394–DQ649409).

Seven haplotypes were observed among the 125 *G. agassizii* from the Mojave population (Table 3). Five localities had a single haplotype, and 1 region, the Northeastern Mojave, had 3 sympatric haplotypes, likely a result of the greater extent of sampling at this locality. One haplotype, MOJ-A01, occurred in all but the Northeastern Recovery Unit. Similarly, haplotype MOJ-B01 was common in the Northeastern and Upper Virgin River recovery units but also occurred in low frequency in the Western Mojave and Eastern Colorado recovery units (Table 3). Haplotype MOJ-A02 occurred in 2 nearby localities in the Southern Mojave. MOJ-A03 was found in the nearby Western Mojave and Southern Mojave recovery units. In contrast, haplotypes MOJ-A04 and -B02 occurred at single locations only. Haplotypes within the Mojave population differed at most by 4–5 bp, or only 0.6%, and haplotypes MOJ-B01–03 differed from one another by 1–2 bp only, as did MOJ-A01–04.

Maternal History. — The phylogenetic evaluation was based upon 60 potentially cladistically informative nucleotide positions. In total, 842 nucleotide positions did not vary between the outgroup and ingroup taxa. Autapomorphies occurred at 22 nucleotide sites. The cladistic analysis of the sequences yielded 2 most parsimonious solutions (length = 77 steps, CI = 0.81, RI = 0.95, RC = 0.76). By using *G. flavomarginatus* as the primary outgroup, *G. berlandieri* was resolved as the sister group to all maternal lineages of *G. agassizii*. The consensus trees (Fig. 2) had 2 strongly supported lineages at the base of the tree, one containing Sonoran samples and the other containing samples from the Mojave population. Within the Mojave population, 2 major sublineages were resolved: Haplogroup A, "broadly distributed," and Haplogroup B, Northeastern Mojave. Both lineages contained 1 haplotype that was relatively broadly distributed (Table 3), along with alternative haplotypes. The 2 most basal nodes for *G. agassizii* were strongly supported having bootstrap proportions of 100% and decay indices of 9–10 steps for the Sonoran and Mojave lineages, respectively (Fig. 2). Within the Mojave, Haploclades A and B were only weakly supported; bootstrap proportions = 53%–65% and decay values were 1–2 steps.

When using MRMODELTEST, the general time reversal plus invariant sites (GTR + G) model was selected for use in the Bayesian inference analysis (–lnL = 2111.7654; K = 9; AIC = 4241.5308). Bayesian inference resulted in

Table 3. The distribution of mitochondrial deoxyribonucleic acid haplotypes from the Mojave desert tortoise, *Gopherus agassizii*.

Desert region/ recovery unit[a]	Group	Haplogroup A				Haplogroup B			Total
		MOJ-A01	MOJ-A02	MOJ-A03	MOJ-A04	MOJ-B01	MOJ-B02	MOJ-B03	
Western Mojave	1	2				1			3
	2	10		1					11
Central Mojave	3	6							6
	5	2							2
Southern Mojave	6	6	2						8
	7	7		1					8
	8	3							3
	9	5	1						6
	10	6							6
Northeastern Mojave	11					40	1	6	47
Eastern Mojave	12	8							8
Northern Colorado	13	3			1				4
Eastern Colorado	14	6				1			7
Upper Virgin River	15	1				4		1	6
Total		65	3	2	1	46	1	7	125

[a] Within the Mojave Desert, 2 major sublineages were resolved: Haplogroup A "broadly distributed", and Haplogroup B, Northeastern Mojave (Fig. 2). The greater relative sampling in the Northeastern Mojave (group 11) reflected an attempt to locate a haplotype from Haplogroup A.

a tree that was identical to the maximum parsimony consensus trees. The Bayesian posterior probabilities were higher than the bootstrap proportions (Fig. 2).

Microsatellite Evaluation. — Of the 16 loci surveyed in 628 desert tortoises (Table 1), 11 were highly variable and informative: Goag03, Goag04, Goag06, Goag07, GP15, GP19, GP30, GP55, GP61, GP81, and GP102. Five loci showed insufficient variation and were excluded from our analyses: GP26, GP96, Cm58, Goag05, and Goag32. For locus Goag03, only 2 study sites exhibited variation: groups 11 and 15 (Northeastern Mojave and the Upper Virgin River recovery units, respectively). For all microsatellite loci used in this study, individual genotypes were summarized by regional groups and are available from the Internet home page of RWM (www.zoo.utoronto.ca/drbob/publications).

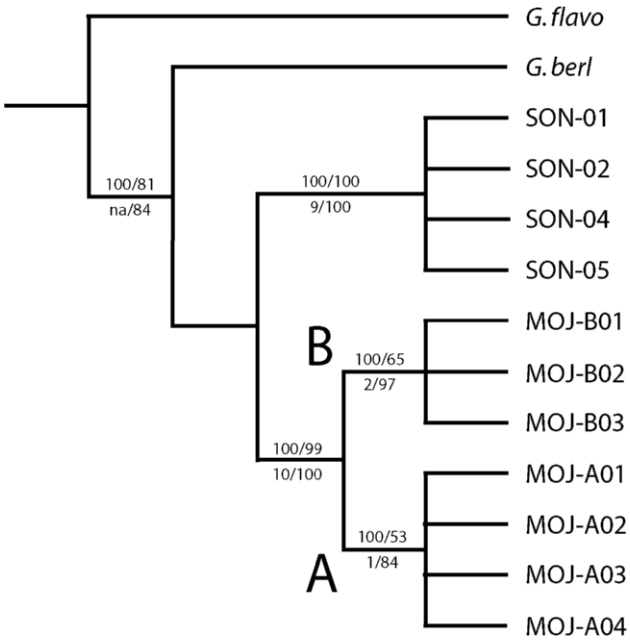

Figure 2. A 50% majority rule consensus tree based on maximum parsimony and Bayesian inference evaluations of the mitochondrial deoxyribonucleic acid sequence data from tortoises, genus *Gopherus*. SON = Sonoran and MOJ = Mojave populations of the desert tortoise (*Gopherus agassizii*) and outgroups G. berl (*G. berlandieri*) and G. flav (*G. flavomarginatus*). Numbers above the branches are given as frequency of resolution in the maximum parsimony evaluation/bootstrap proportions, and below as Bremer support/Bayesian posterior probabilities. Na = not applicable, and letters at nodes denote haplogroup lineages of Mojave populations discussed in text.

Major differences occurred between repeat motifs at some microsatellite loci in *G. agassizii* when compared with species or the population for which the locus was originally isolated, including GP19, GP30, GP61, GP81, and GP102 (Table 2). We were not able to precisely determine the motif for GP102 in *G. agassizii*. Homozygous amplicons were vague in the middle of the sequences, suggesting that 2 alleles were present. Fragment analysis did not allow determination of a heterozygous state (difference in repeat motifs) when amplicon lengths were equal. We did not clone these products to determine the competing sequences but rather made an arbitrary assignment of repeat numbers. Consequently, data for GP102 were not necessarily reflective of all possible heterozygous states.

Locus GP61 exhibited 2 different motif states; alleles having more than 16 repeats had a simple dinucleotide motif, $(GT)_{16+}$. However, alleles scoring in the range of 10–12 repeats had a compound motif, $(GT)_4AT(GT)_6$. As in the Sonoran population (Edwards et al. 2004), heterozygous individuals had both motifs. The simple motif had a greater range of allelic states than the compound motif.

Schwartz et al. (2003) originally described the compound motif for GP19 in *Gopherus polyphemus* as $(GT)_9/(GT)_3(GA)_6$. We found a dramatically derived state

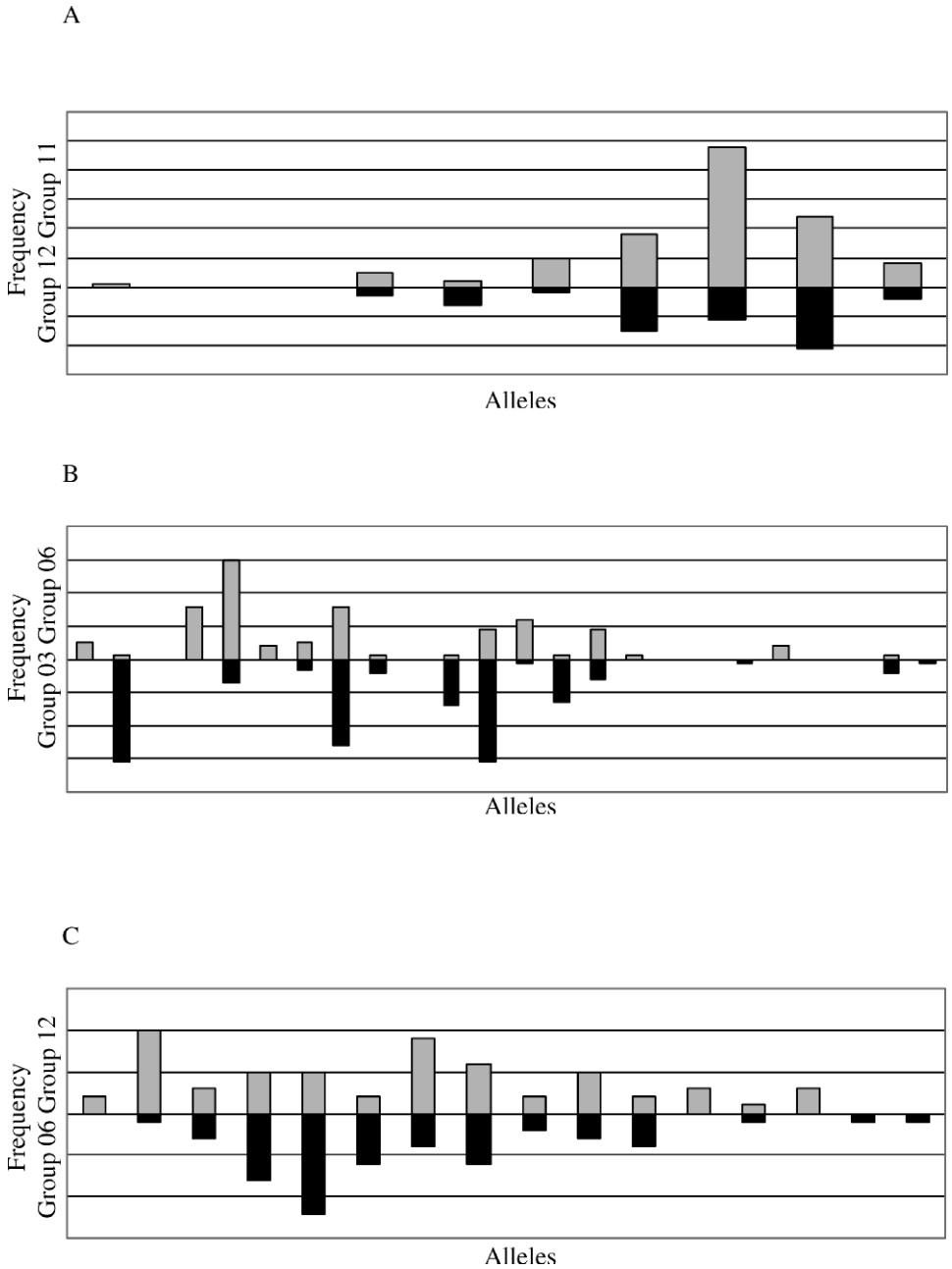

Figure 3. Comparison of allelic frequencies between sample groups of desert tortoises, *Gopherus agassizii*, from the Mojave population by using the G-based exact test for genotypic differentiation. Sample groups refer to Table 1. A: Locus GP81, $p = 0.024$, SE = 0.002; B: Locus GP102, $p < 0.001$, SE < 0.001; C: Locus Goag04, $p = 0.031$, SE = 0.003.

in our Mojave samples of *G. agassizii*, such that allele 11 sequenced as $(GT)_3/(GT)_2GAAA(GA)_4$ and allele 21 sequenced as $(GT)_7ATGTATGT/(GT)_2GAAA(GA)_5$. Consequently, we could not use analyses that required a stepwise mutation model, such as R_{ST} (Slatkin 1995).

Some dinucleotide loci exhibited imprecise pherograms (e.g., stutter peaks) when the number of repeats exceeded 25. A score of "35" could not be differentiated from "34" or "36". Consequently, pherograms were scored by using a standardized rule set for consistency with error on the conservative side. Loci GP15, GP61, GP102, and Goag06 may have reached the upper limits of our ability to detect repeat numbers, because larger amplicons had very low intensity pherograms. Generally, alleles with more than 55 repeats were not scored, and, thus, we likely missed some alternative alleles.

The distributions of allele size classes for most loci were not normally distributed. Some were highly skewed, and others exhibited multiple peaks (Fig. 3). Unique and private alleles were detected in several sample groups at some of the more variable loci. In some cases, private alleles comprised a high proportion of the alleles observed within a population. For example, sample group 14 had 4 alleles at GP30; the private allele composed 25% of all alleles (Table 4) but it occurred at a frequency of < 5%.

Table 4. Distribution of unique and private alleles in 15 sample groups (summarized in Table 1) of desert tortoises from the Mojave population.[a]

Sample group	GP61			GP19			GP102			GP30			GP55			GP15			GP81			Goag4			Goag06			Goag7			Goag3		
	T	U	%	T	U	%	T	U	%	T	U	%	T	U	%	T	U	%	T	U	%	T	U	%	T	U	%	T	U	%	T	U	%
1	14			2			7			9	1	11	9			17			7	2	29	16			26			5			1		
2	15			2			14			8	1	13	8	1	13	24	1(1)	4.2	5			17	1	5.9	22			4			1		
3	9			2			9			5			8	1	13	15			5			13			16			4			1		
4	11			2			11			7			11			14			6			12			19			4			1		
5	13			2			11			7	1	14	12	1	8.3	16			5			15			21			5			1		
6	10			2			10			4			6			9			6			13			18			4			1		
7	16			2			13	1	7.7	8	2	25	7			21			7			12			21			4			1		
8	14			2			15			7			11			20	1	5	7	1	14	11			33			5			1		
9	11			2			12			6	1	17	7	1(1)	14	10			7			12			22			5			1		
10	13			2			7	1(1)	14.3	4			7			14	1	7.1	7			9			14			4			1		
11	15			2			16	1	6.3	8			6			19			8	1	13	16			19			6			2		
12	18			2			12			9			7			15			7			14			15	1	6.7	4			1		
13	13	1	7.7	2			12			10	2(1)	20	5			14			7			11	1	9.1	14			5			1		
14	15	1(1)	6.7	2			12	1(1)	8.3	4	1	25	9			13			6			11	1(1)	9.1	21			5			1		
15	11			1			12	1(1)	8.3	7			3			15			5			10			15			3			2		
Total	27			2			24			21			17			37			11			22			49			5			2		

[a] T = total number of allelic states observed in a sample group; U = number of alleles unique to the sample group; parenthetic values are the number of unique alleles that occur at a frequency > 5% (private alleles) in a sample group relative to the total number of alleles; % = the percentage of alleles that are unique in a sample group [(U/T) × 100]. No private alleles in a population occurred at a frequency > 8%.

The frequency of occurrence for the relatively rare, private allele was always ≤ 8%.

Most sample group pairwise comparisons between distributions of allelic frequencies (Fig. 3) were found to be significantly different by the G-based Exact test (Goudet et al. 1996). Three sample groups deviated from H-W in exhibiting a greater number of heterozygotes than expected (Table 5). By using a 5% cutoff, about 1 deviation is expected for each locus, except for Goag3. Three loci showed excessive deviations from expectations in the form of heterozygote deficiencies: GP30, G81, and Goag06. In total, 24.5% of the data points showed deviations from H-W, with 8.6% owing to Goag06 alone (Table 5).

Garnier-Gere's and Dillmann's (1992) test rejected the null hypothesis for linkage disequilibrium (equilibrium for locus pairs) for 45 (of 165) locus pairs within 15 sample groups. Nine sample groups had a percentage of total pairwise comparisons with p-values > 0.05 (range 0.0%–26.7%). However, locus pairs did not consistently exhibit disequilibrium among groups.

Bayesian likelihood values for all runs by using STRUCTURE typically stabilized after 50,000–100,000 iterations after burn-in. The analyses obtained the lowest average Ln for 6 subpopulations (Table 6). These subpopulations were concordant with the recommendations in the *Recovery Plan*. Because substantial differentiation was observed in the Western Mojave Recovery Unit, as revealed by Φ_{ST} values, we removed populations 11–15 and performed a new analysis to reduce the affects of IBD. This analysis suggested that the current Western Mojave Recovery Unit supported 4 subpopulations (Table 6): sample groups 1–2, 3–5, 8, and 6–7 plus 9–10 (Fig. 4).

A 2-dimensional, monotonic MDS plot displayed population differentiation among sample groups (Fig. 5). It had a stress of 1.39, a fair to good fit by Kruskal's and Wish's (1978) index. The 15 sample groups clustered complementary to their geographic proximities, as anticipated when assuming gene flow. Geographically distant sample groups 11 and 15 were noticeably separated from the other groups.

Population assignment tests correctly placed the majority of individuals back to their sample groups with high stringency (Table 7). Individuals not assigned to a sample group were frequently assigned to a geographically nearby group or to one within the same region. Geographically proximate groups 12 and 13 occurred near the boundary of 2 desert regions, the eastern Mojave Desert and northern Colorado Desert (Fig. 1). The population assignment evaluations had difficulty distinguishing individuals between these 2 recovery units. Whereas, 80% of the samples from group 11 were correctly assigned, only 48% of 31 samples from group 12 were correctly assigned. However, 87% of tortoises from group 12 were correctly assigned to groups 12 and 13 combined, indicating that, in this case, geographic proximity was a better predictor of genetic structuring

Table 5. Summary of deviation from Hardy-Weinberg expectations for 11 variable microsatellite loci and 15 sample groups of the desert tortoise, *Gopherus agassizii.* Sample groups refer to Table 1.

Locus	No. comparisons	No. heterozygote excess	No. heterozygote deficiency	Range in no. of repeats
GP61	15	0	2	11–38
GP19	14	0	0	11–21
GP102	15	1	1	19–42
GP30	15	0	7	10–17
GP55	15	0	3	7–30
GP15	15	0	2	13–52
GP81	15	0	6	16–28
Goag4	15	1	0	12–32
Goag06	15	0	13	17–67
Goag7	15	1	0	13–28
Goag3	2	0	0	6–7

than recovery unit. A similar trend was discovered for tortoises in group 13.

When sample groups were combined to reflect current recovery units, and when sample groups 12 and 13 were combined, assignment scores of $\geq 80\%$ were obtained (Table 7). For the Western Mojave Recovery Unit, we deleted geographically distant sample groups (1, 2, 11–15) and re(-)ran the assignment test. We combined samples 3–5 and samples 6–10, because they had higher proportions of misassigned individuals than all other units (Table 7). Although not given in Table 7, the percentage of individuals correctly assigned to the proposed Central Mojave (samples 3–5) and Southern Mojave (samples 6–10) recovery units combined was 52% each, with 24% being assigned to the combined unit as the second most likely assignment and 13% assigned to the adjacent Western Mojave Recovery Unit.

Finally, we combined the sample groups to reflect geographic regions, which reflected the current recovery units (Table 7). This treatment recognized variation within the Western Mojave Recovery Unit. In total, 8 regions were identified. Assignment scores ranged from 59.6% to 95.7%. The more fine-grained analyses, those that included a greater number of subdivisions, yielded lower assignment scores.

Geographic substructuring was further assessed by breaking and recombining specific units. The assignment tests produced 96%–98% accuracy when the distribution of tortoises was divided into 2 groups: Northeast (11, 15) and Central (1–10, 12–14), respectively. When geographically proximate groups were split and recombined, the assignment tests invariably decreased, some to less than 50% (sample groups 2, 6, and 8).

The hierarchical analysis of molecular variance indicated the absence of panmixia; significant genetic structuring was discovered. The AMOVA revealed that 93.9% ($p < 0.001$) of the observed variation was partitioned among individuals within sample groups ($\Phi_{IT} = 0.939$), whereas only 6.1% of the variation was among the sample groups ($\Phi_{ST} = 0.061$, $p < 0.001$). The positive significant correlations between genetic distance (pairwise Φ_{ST}) and geographic distance accounted for approximately 65% of the observed variation (Mantel test; $r^2 = 0.646$, $p = 0.002$).

By using BOTTLENECK, we detected a significant excess in heterozygosity in 2 sample groups, 11 and 15, the Northeastern Mojave and Upper Virgin River recovery units. The Wilcoxon Test with the (infinite alleles model [IAM]) detected an excess in both groups but the Sign Test (IAM) method of Piry et al. (1999) identified group 15 only. No deficit or excess in heterozygosity was detected when the data for all groups were combined. All sample sets fit the expected beta distribution (Cornuet and Luikart 1996), thus providing no evidence for bottlenecking. By using the method of Garza and Williamson (2001) to detect potential reduction in population size, all values of M fell above the critical value M_C. However, the results may not be reliable, because this test assumed stepwise mutation.

Human-Mediated Translocations. — Native Americans undoubtedly moved desert tortoises from one place to another (as implied in Schneider and Everson 1989). The distances were probably limited, except for annual gatherings for mourning ceremonies (i.e., Las Vegas Band, Southern Paiute: Kelly, no date) and the result may have been death for the tortoises.

Throughout the 20th century, tortoises were captured for domestic pets and were translocated for various purposes. Captive tortoises currently or formerly kept by residents of desert communities often escape or are deliberately released into adjacent desert lands. The sources of the captives may or may not be local relative to the point of escape or release. Escaped captives are so common that a publication gives actions to take when a former captive is found (Berry and Duck, 2006). Captives have been observed wandering within city limits or nearby in Ridgecrest, Barstow, Ft. Irwin, Victorville, and Twentynine Palms in the Western Mojave Recovery Unit; Needles in the Eastern Mojave Recovery Unit; Las Vegas in the Northeastern Mojave Recovery Unit; and St. George in the Upper Virgin River Recovery Unit. Tortoises are often taken to or released at protected areas such as parks and Natural Areas (Howland 1989; Ginn 1990; Jennings 1991; Connor and Kaur 2004).

Thousands of tortoises were released in the southwestern deserts by humane societies, California Department of Fish and Game, Nevada Department of Wildlife Resources, Utah Division of Wildlife Resources, State and National Park personnel, academicians and others (Fig. 6). Data are limited before the 1960s, but releases were documented for California and Utah (Hardy 1945; Woodbury and Hardy 1948; Jaeger 1950, 1955). Woodbury and Hardy (1948) surveyed Beaver Dam Slope, Utah (Northeastern Mojave Recovery Unit) for tortoises between 1936 and 1946. At least 6.1% of 281 tortoises found showed signs of previous captivity. Releases also occurred in the

Table 6. Inferred population structure obtained from the software program STRUCTURE 2.1 for all samples, and for a subset of samples from the current Western Mojave Recovery Unit (sample groups 1–10).[a]

All samples (n = 628)	Ln (variance below)				
K	Run 1	Run 2	Run 3	Run 4	Average Ln
1	–25,140.5	–25,144.0	–25,143.6	–25,143.3	–25,142.9
	99.7	106.1	106	105.8	
2	–24,362.2	–24,360.6	–24,360.8	–24,361.2	–24,361.2
	463.9	460.7	462.6	463.3	
3	–23,644.7	–23,646.2	–23,647.9	–23,648.6	–23,646.9
	568.4	570.5	572.8	574.9	
4	–23,283.3	–23,275.4	–23,269.5	–23,272.6	–23,275.2
	827.5	810.6	800.5	804.8	
5	–23,134.7	–23,038.1	–23,030.7	–23,042.5	–23,061.5
	1049.5	1056.0	1041.2	1062.6	
6	–22,881.4	–22,886.7	–22,883.4	–22,893.2	–22,886.2
	1249.2	1260.3	1251.2	1275.1	
7	–23,042.2	–22,840.3	–24,213.8	–24,745.5	–23,710.5
	1921.8	1521.7	4220.5	5220.9	
8	–22,901.4	–23,454.5	–23,144.8	–22,964.3	–23,116.3
	1712.3	3043.6	2204.3	1858.5	
9	–23,538.9	–24,007.6	–22,951.0	–23,041.1	–23,384.7
	3494.4	4412.3	2335.7	2230.9	
10	–22,857.7	–24,696.7	–22,900.7	–22,900.7	–23,339.0
	2208.1	5872.7	2262.5	2280.9	
11	–23,305.8	–24,272.3	–24,176.7	–24,377.2	–24,033.0
	3318.1	5406.3	5027.1	5490.7	
12	–23,236.8	–24,848.4	–23,590.5	–34,317.7	–26,498.4
	3426.8	6666.9	4129.0	25,502.9	
13	–24,346.5	–23,339.1	–34,657.2	–28,975.2	–27,829.5
	5879.4	3820.1	26,339.3	15,064.1	
14	–31,546.3	–560,553.8	–31,303.2	–24,971.2	–162,093.6
	20,362.5	1,077,674.6	19,809.4	7242.0	
15	–133,340.8	–28,256.8	–27,197.9	–41,616.9	–57,603.1
	223,973.3	13,936.0	11,869.1	40,664.7	
Western Mojave samples (n = 459)					
K	Run 1	Run 2	Run 3	Run 4	Average Ln
1	–17,343.6	–17,342.7	–17,338.4	–17,339.0	–17,340.9
	99.8	97.2	90.7	90.8	
2	–16,870.6	–16,871.0	–16,870.0	–16,873.2	–16,871.2
	405.0	406.7	405.5	411.5	
3	–16,968.7	–16,715.6	–16,722.3	–16,626.4	–16,758.3
	1218.3	693.6	847.8	657.2	
4	–16,438.7	–16,434.3	–16,432.9	–16,438.4	–16,436.1
	874.5	863.0	860.4	871.3	
5	–16,380.9	–16,404.5	–16,419.0	–18,206.9	–16,852.8
	1068.9	1114.4	1143.6	4629.7	
6	–16,742.5	–16,392.3	–16,418.5	–17,106.1	–16,664.9
	1876.6	1163.9	1217.5	2750.5	
7	–16,778.8	–17,811.3	–16,450.6	–18,021.6	–17,265.6
	2430.1	4440.4	1540.5	4871.7	
8	–16,343.7	–18,314.1	–18,520.9	–16,417.4	–17,399.0
	1837.0	5698.8	5924.8	1746.6	
9	–20,559.6	–17,456.7	–16,346.8	–19,067.6	–18,357.7
	10,289.0	4207.3	1842.1	7354.0	
10	–18,184.4	–406,665.0	–19,777.8	–21,971.6	–116,649.7
	5770.3	780,420.0	8955.7	13,321.4	

[a] K = the number of populations set as the a priori for the simulation; Ln = the log likelihood of the data averaged over all iterations after burn-in (with variance reported below); and the average Ln for all 4 runs for a given simulation. (For all simulations: 250,000 iterations per run with a burn-in of 5000).

vicinity of St. George and the Upper Virgin River Recovery Unit (Hardy 1945).

From the late 1960s to the mid 1970s, the California Department of Fish and Game sponsored numerous captive releases and kept records for > 800 individuals (Fig. 6). Their last official release was the rehabilitation experiment at the Quarterway and Halfway Houses in the Living Desert Reserve and Ft. Soda, respectively, in the late 1970s. Among 200 tortoises initially in the program, 30 survived, only to be moved to private lands in the Antelope Valley (Cook et al. 1978; Weber et al. 1979; Cook 1983).

In Nevada, the first documented releases of captive tortoises occurred on the Desert Game Range in 1973 (B.L. Burge, *pers. comm.*, December 2005; Fig. 6). In the late 1970s and early 1980s, employees of the Nevada

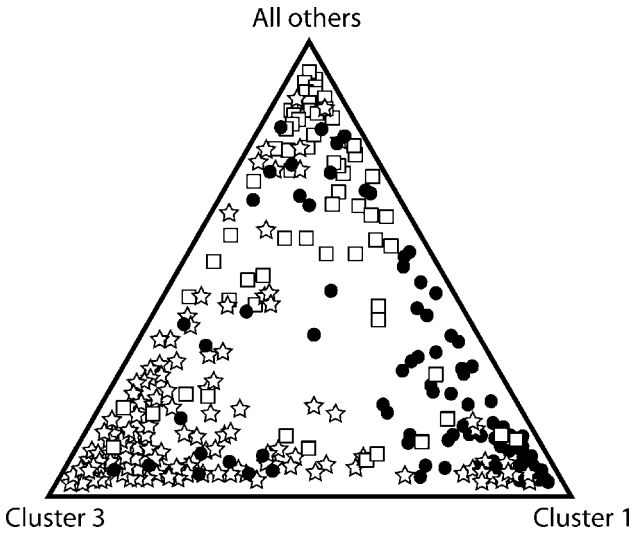

Figure 4. Triangle plot of the estimated membership coefficients for each individual in the Western Mojave Recovery Unit. Symbols correspond to sampling groups (given in Table 1) when the number of populations (K) is K = 3: circles = sample groups 1 and 2, squares = sample groups 3–5, stars = sample groups 6–10. Note the general clustering in the corners of each group and the overall pattern of admixture (gene flow). The cluster of stars in the circle samples depicts individuals mostly from Group 8, which is geographically the most proximate to the circle sample group.

Department of Wildlife Resources released hundreds of captive tortoises onto desert lands (R.J. Turner, *pers. comm.*, December 2005).

State and federal agencies approved the release of numerous captive and wild tortoises in 1997 at a long-term release site in southern Nevada (Field 1999). Additional translocation projects occurred throughout Nevada between 1990 and 2005 (Corn 1991; Nussear 2004; Charles Le Bar, *pers. comm.*, December 2005).

Between 1973 and 1983, the Utah Division of Wildlife Resources released at least 195 captive tortoises on Beaver Dam Slope (Coffeen, *pers. comm.*, December 2005; Coffeen 1984, 1985). In 1980, a general survey conducted throughout 324 km^2 of the area revealed that 21.9% of 105 located tortoises were marked captives (Minden 1980). Tortoises were also released on the historical Woodbury and Hardy (1948) site; when the study site was surveyed in 1981, 23.3% of the 73 tortoises observed were marked captives (Minden and Keller 1981). In the mid to late 1980s, captive tortoises were released in the Upper Virgin River Recovery Unit at Grapevine Pass and Red Cliffs Recreation Area (Coffeen 1986); 71 captive tortoises were also released at Hurricane Cinder Knolls (McLuckie, unpubl. data, 2006).

Evidence exists of a substantial transfer of tortoises from the western Mojave Desert in California to Utah. In April of 1970, 2 wardens arrested a commercial collector who claimed to have taken thousands of tortoises from the Western Mojave Recovery Unit of California between the 1960s and April 1970 and sold them commercially in Salt Lake City, Utah (Berry 1984). Some of these tortoises may have been released on the Beaver Dam Slope and north of St. George in the 1970s and early 1980s in what are now the Northeastern Mojave and Upper Virgin River recovery units.

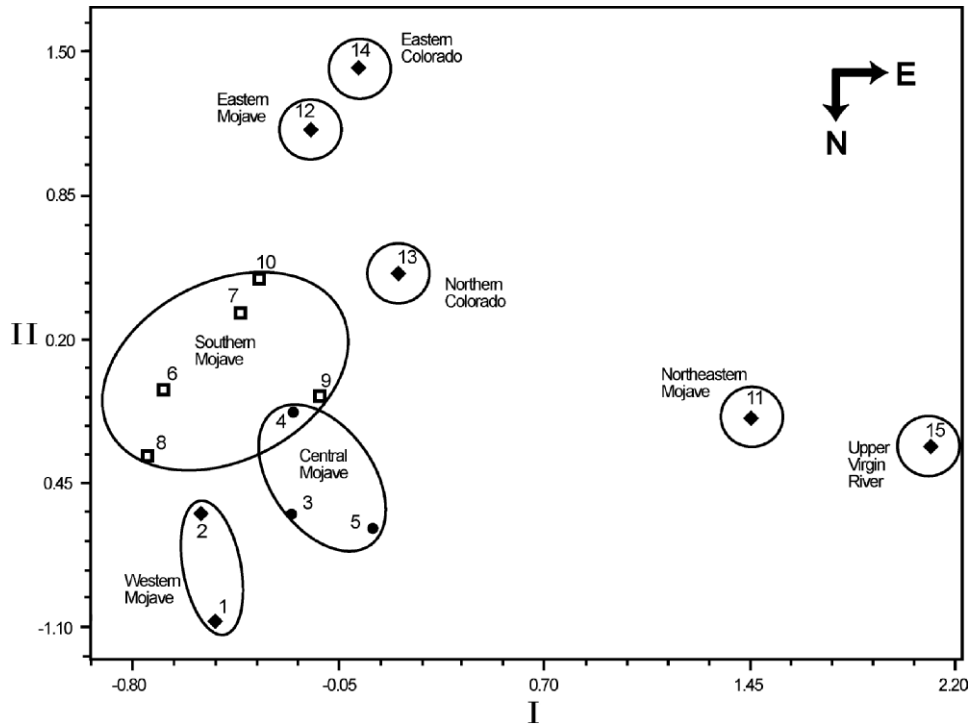

Figure 5. A 2-dimensional scaling plot of genetic distances (Φ_{ST}) for 15 sample groups of desert tortoises, *Gopherus agassizii*, from the Mojave population. Open squares and solid circles indicate samples from the southern and central Mojave Deserts, respectively.

Table 7. Population assignment tests for desert tortoises from the Mojave population and 8 desert regions or recovery units. The initial evaluation treated all 15 sample groups separately. The second treatment combined tortoises into units reflecting the recovery units recommended in the 1994 *Recovery Plan* except for combining sample groups 12 and 13. The third treatment considered populations on the basis of existing and proposed recovery units.

Sample group	No. samples	No. correctly assigned	% Correctly assigned	% With LOD > 2[a]	No. assigned to same region or neighboring group	% Assigned to same region
1	62	42	67.7	58.1	8	80.6
2	83	26	31.3	19.3	16	50.6
3	19	10	52.6	47.4	3	68.4
4	31	11	35.5	22.6	11	71.0
5	47	25	53.2	51.1	12	78.7
6	26	12	46.2	42.3	11	88.5
7	71	20	28.2	19.7	37	80.3
8	74	34	45.9	35.1	13	63.5
9	27	8	29.6	14.8	14	81.5
10	19	10	52.6	52.6	5	78.9
11	60	48	80.0	78.3	0	80.0
12	31	15	48.4	38.7	12 (to group 13)	87.1
13	18	10	55.6	27.8	3 (to group 12)	72.2
14	37	28	75.7	59.5	0	75.7
15	23	22	95.7	91.3	0	95.7
Combined groups						
15	23	23	100			
11	60	51	83.3	10		
12, 13	49	41	81.6	8.2		
14	37	35	91.9	5.4		
1–10	459	377	80	8.5		
Region						
Western Mojave	164	139	84.8			
Central Mojave	97	66	68.0			
Southern Mojave	198	118	59.6			
Northeastern Mojave	60	49	81.7			
Eastern Mojave	31	17	54.8			
Northern Colorado	18	13	72.2			
Eastern Colorado	37	33	89.2			
Upper Virgin River	23	22	95.7			

[a] LOD = log of the odds ratio.

DISCUSSION

Maternal History. — Two distinctive maternal lineages exist, one associated with the Sonoran population in Arizona and the other with the Mojave population. By using *G. flavomarginatus* as the outgroup, the sister group to *G. agassizii* was *G. berlandieri* (Fig. 2). This resolution differed from that of Lamb et al. (1989). Rooting with the same outgroup, they found that the Sonoran *G. agassizii* was the sister group of *G. berlandieri* and exclusive of the Mojave population. The difference could have resulted from several factors. Lamb et al. (1989) evaluated restriction fragment length polymorphisms, and we used more precise sequences. They also had greater taxonomic and geographic sampling. Although we might have reached a similar conclusion if we had used the same coverage, this was unlikely. The difference likely resulted from their use of presence/absence coding of nonhomologous fragment lengths.

Within Mojave population samples, little differentiation occurred among the 7 haplotypes (Fig. 2). Two primary maternal sublineages occur in the Mojave population, but the minor level of differentiation was not indicative of taxonomic differentiation. In contrast, the substantial sequence differentiation between Mojave and Sonoran (Arizona) populations is consistent with the hypothesis that *G. agassizii* consists of more than one species (Berry et al. 2002).

Descriptive Statistics of Microsatellite nuclear DNA (nDNA). — The motif differences in interspecies amplification of microsatellite loci indicated that evaluation of data required species-specific and even population-specific sequence information. Loci amplified between species (and within species too; Estoup et al. 2002.) did not necessarily follow assumptions of the stepwise mutation model.

Deviations from H-W could have several sources. Excess of homozygotes at some loci (e.g., Goag06) could have resulted from nonamplifying alleles, as a consequence of motif anomalies. Translocations of tortoises throughout the Mojave population also might have contributed to the excess of heterozygosity. For cases of heterozygotic deficit, ambiguities associated with high numbers of repeats might have artificially inflated the number of observed homozygotes or elevated Φ_{IS} values if translocated tortoises had very different allele frequencies

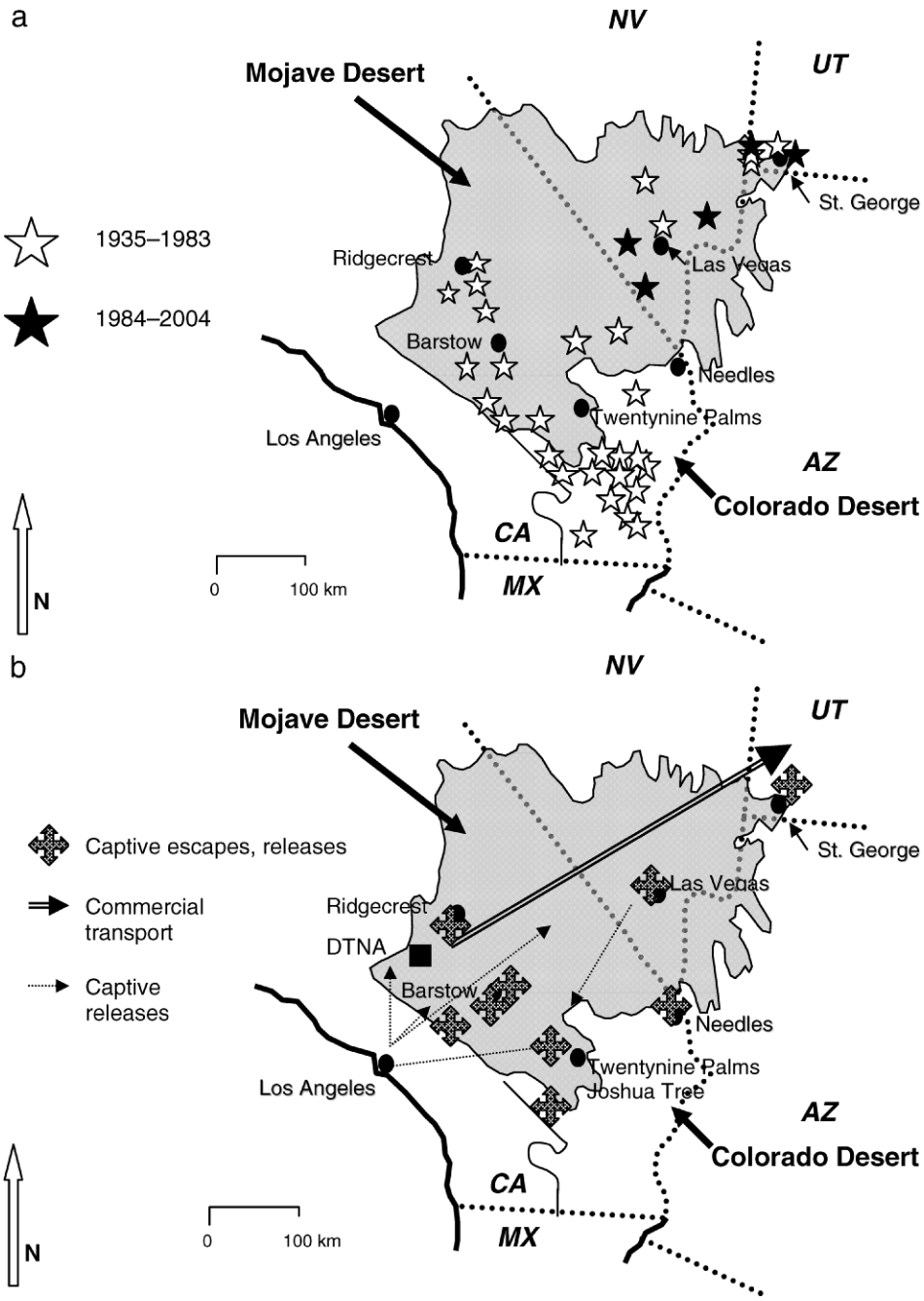

Figure 6. (a) Locations of captive desert tortoises, *Gopherus agassizii*, released by the California Department of Fish and Game, Nevada Department of Wildlife, Utah Division of Wildlife Resources or by others, as described in government reports and university theses and dissertations. The shaded area indicates the limit of the Mojave Desert. (b) Locations of areas where captives escaped or were released outside of desert towns. Tortoises were taken from the Los Angeles basin and released at places such as the Desert Tortoise Research Natural Area (DTNA) or Joshua Tree National Park. There were also large-scale commercial transfers of tortoises.

(a Wahlund effect, lower than expected heterozygosity owing to population substructuring). Technical difficulties of accurately scoring heterozygotes with high numbers of repeats surely contributed to the estimates of heterozygosity deficiencies at Goag06 and possibly at other loci (Table 5). Unfortunately, the proportions of misscored loci cannot be accurately partitioned from the data set to examine for a Wahlund effect (e.g., Chapuis and Estoup 2007).

In total, 24.5% of the data points showed deviations from H-W in the form of heterozygote deficiencies (Table 5). Such deviations may not significantly affect our conclusions. Dankin and Avise (2004) showed that 20% of the data points can deviate from H-W, without affecting the accurate determination of parentage. Empirically, the great correspondence between the results of the microsatellite analyses and ecological boundaries supports our

assumption of the utility of the data irrespective of their deviations from H-W expectations.

For tortoises, IBD (isolation-by-distance) affected the probability of individuals mating with one another and violated the assumption of panmixia for statistical tests. Significant pairwise associations of some loci (Table 5) may have reflected an absence of panmixia (i.e., a Wahlund effect), mating systems or problems in resolving alleles. However, because significant linkage disequilibrium was not observed in all groupings, this explanation was unlikely. The greater than expected deviations from H-W were strongly paralleled by Φ_{IS} values. Some deviations from H-W owed to technical constraints (e.g., Goag06), but this was unlikely for other loci (e.g., GP30, GP81). Some positive inbreeding coefficients and departures from H-W may have been because of population structure. However, inbreeding was unlikely to have occurred because most loci did not have significant Φ_{IS} values within a sample group.

Gene Flow. — Genetic structuring was strongly associated with geography (Slatkin and Maddison 1990), IBD, and the limited dispersion of individual tortoises (Mantel test; $r^2 = 0.646$, $p = 0.002$). The results of the AMOVA indicated the absence of panmixia. IBD was also reported by Britten et al. (1997) for allozyme and mtDNA data, and by Edwards et al. (2004) for Sonoran tortoises. Microsatellite variability was greater within than among sample groups, suggesting that the Mojave metapopulation was relatively homogeneous, i.e., the common alleles were broadly distributed. Gene flow likely occurred throughout populations in California, at least until the recent proliferation of anthropogenic barriers. The distribution of low-frequency, unique microsatellite alleles supported the hypothesis that the genetic structure resulted from gene flow and not common ancestry. Indeed, Edwards et al. (2004) noted that desert tortoises were ideal organisms for applying the IBD model, because they are distributed across the landscape in patches, and the difficulty of dispersion is a function of geography.

Bottlenecking. — The excess of heterozygosity in samples from the Northeastern Mojave and Upper Virgin River recovery units could have resulted from recent bottlenecking. However, this possibility was not supported by the ratio of the total number of alleles to the overall range in allele size. Population declines in the Northeastern Mojave and Upper Virgin River recovery units have been well documented in recent years (USFWS 1980; Minden and Keller 1981; Fridell and Coffeen 1993; McLuckie et al. 2004). Although other regions also experienced population declines (Berry and Medica 1995; Brown et al. 1999; Christopher et al. 2003), they did not show genetic evidence of bottlenecks. This inconsistency may have been because of at least 4 factors. First, our samples were collected over 10 years and this could have precluded the effects of recent declines. Second, the time frame for sampling may have been too short for observing a shift in heterozygosity for a long-lived species with a long generation time. Garrigan and Hedrick (2003) reported that 5–10 generations were required to genetically detect bottlenecks. Moreover, Dinerstein and McCracken (1990) did not see bottleneck effects in the greater one-horned rhinoceros by using microsatellite DNA, despite well-documented evidence. Consequently, conclusions on the genetic structure of populations should not be based on molecular evidence alone but should accompany field observations. Third, polyandry, if common, and especially when combined with sperm storage, could have increased the effective population size (Sugg and Chesser 1994). Sperm storage for up to 3 years has been documented in the desert tortoise (Palmer et al. 1998) and anecdotal evidence suggests that it may occur for much longer. (One isolated captive female tortoise produced viable clutches for 15 years after her last known association with a male tortoise; P. Gould Glasco, *pers. comm.*, May 2006.) A controlled investigation of polyandry in the western Mojave Desert found that all females produced polyandrous clutches over a period of 2 years (Murphy, Edwards, Bratton, and Hagen, in prep.). And fourth, the observed increase in heterozygosity in the Northeastern Mojave and Upper Virgin River recovery units may also be a reflection of translocated tortoises. The translocation of gravid females or those that were storing sperm would serve to compound the possible explanations for excess heterozygosity.

Human-Mediated Translocations. — Translocations and releases of animals, especially if uninformed, can have negative genetic consequences (Allendorf and Luikart 2007). The historical releases and translocations of tortoises could have affected our results in the form of deviations from the H-W, increased heterozygosity and estimates of recent gene flow, anomalous distributions of some haplotypes, and increased Φ_{IS} values (through a Wahlund effect). The geographically disjunct occurrence of some haplotypes (MOJ-A01 with -B01 and -B03 in the Upper Virgin River; Table 3) could be caused by translocations. Because the widespread MOJ-A01 haplotype was absent in our initial survey of 7 tortoises in the Northeastern Recovery Unit only, we sequenced 40 additional samples: in total, 40 were MOJ-B01, 6 were MOJ-B03, and 1 was MOJ-B02. Because MOJ-A01 was absent from the Northeastern Recovery Unit, its presence in Upper Virgin River Recovery Unit was likely because of relocated tortoises. Our samples from the Northeastern Mojave were taken from relatively remote areas where the releases of captives were less likely.

Several other incidences of geographic mixing are evident: MOJ-B01 is geographically and genealogically associated with other members of Haplogroup B, but it also occurs in sympatry with Haplotypes MOJ-A01 (Haplogroup A) in the Western Mojave Recovery Unit (Table 3), specifically at the Interpretive Center at the Desert Tortoise Research Natural Area. This finding is concordant with documentation of multiple captive tortoise releases at the Natural Area (Howland 1989; Ginn

1990; Jennings 1991; Connor and Kaur 2004). Haplotype MOJ-B01 also occurs with MOJ-A01 in the Eastern Colorado Recovery Unit. Very long distance dispersion is the alternative explanation for the widespread occurrence of some haplotypes. Given the extent of documented translocations, the dispersion hypothesis is unlikely, particularly because our data lack other evidence of population expansion or recent ancestry.

Translocated tortoises could compromise the genetic integrity of a population by disruption to coadapted gene complexes in local environments or loss of fitness through outbreeding depression. In particular, Beaver Dam Slope, Utah, has a high frequency of released captive tortoises (Woodbury and Hardy 1948, Minden 1980, Minden and Keller 1981). Although we do not have genetic samples from this area, the excess of heterozygotes in the adjacent Upper Virgin River and Northeastern Mojave recovery units, in the absence of a decrease in the ratio of the total number of alleles to the overall range in allele size, could reflect first- or second-generation offspring from translocated tortoises. A similar problem may exist at the Desert Tortoise Research Natural Area and Joshua Tree National Park in the Western Mojave Recovery Unit. Outbreeding depression can lead to reduced fitness via disease in hybrid populations (Goldberg et al. 2005, Allendorf and Luikart 2007). The high levels of assignments of tortoises to the correct region (Table 7) indicate that, in some cases, survival rates of released tortoises may be low, e.g., the early California reintroduction experiments (Cook et al. 1978; Cook 1983; Weber et al. 1979).

Regional Differentiation. — The STRUCTURE analysis identified from 5 to 8 genetically structured units. These findings support the hypothesis of population structure in the *Recovery Plan* and the Desert Wildlife Management Units described in the Western Mojave Recovery Unit. When considering the close geographic proximity of some of our sample groups (e.g., groups 12 and 13), this result was consistent with our assumption that the Mojave population is genetically structured and that these genetic data were informative for designating recovery units. Sample group 8 may have the most admixture between the "Central" and "Southern" areas of the Western Mojave Recovery Unit. This subanalysis suggested that the Western Mojave Recovery Unit could be subdivided into at least 3 geographic groups. Although STRUCTURE is not a good measure of structure in populations that exhibit nonlinear patterns of IBD (Pritchard et al. 2000), the findings were congruent with the *Recovery Plan* and natural barriers to gene flow. Thus, we used these results as evidence for the assessment of recovery units.

The null hypothesis of a single, homogeneous, panmictic Mojave population was rejected. Although most alleles were broadly distributed, most sample groups significantly differed from one another in allelic frequencies (Table 7). Because the G-based exact test is sensitive to different sample sizes, as in our data, the imbalance in samples might have accounted for the high number of significant differences. However, this does not appear to be true. Most individuals ($> 80\%$) were reassigned (Table 7) back to their sample group. The accuracy of the assignments implies genetic divergence.

The population assignment was viewed as a conservative result. Our data set was limited to 11 variable microsatellite loci only. Additional loci would have likely increased the accuracy of the assignments and the distinctiveness of each recovery unit.

Congruent patterns of genetic differentiation from different regions or taxa lend credence to conclusions. Comparatively, desert tortoises from Mojave and Sonoran populations had almost identical genetic structuring at local and regional levels. The AMOVA of microsatellites from the Sonoran population revealed that 96.3% ($p < 0.001$) of the diversity occurred in individuals within study sites ($\Phi_{IT} = 0.963$), whereas only 3.7% ($p < 0.001$) of the variation was among sites ($\Phi_{ST} = 0.037$) (Edwards et al. 2004). The same result occurred in a geographically equivalent sized subset of our data; $\Phi_{ST} = 0.037$ ($p < 0.001$). In both studies, a significant positive correlation occurred between genetic distance (pairwise Φ_{ST}) and geographic distance.

Recovery Units Revisited

The authors of the *Recovery Plan* proposed 6 recovery units to capture the known genetic, morphological, ecological, and behavioral diversity in desert tortoises as of 1993 (USFWS 1994). Their original objectives agree with the views of Crandall et al. (2000), specifically to preserve the options for adaptive diversity and evolutionary processes, maintain a network of populations, reduce the likelihood of further contraction of the geographic range, and minimize homogenization of the gene pool or pools by anthropogenic activities. The recovery units in the *Recovery Plan*, with some exceptions described below, appear to reflect natural, biological differences in populations and to fall within the DPSs described in government policy (US Department of the Interior and US Department of Commerce 1996).

We emphasize, however, that the genetic evidence presented here is not necessarily concordant with or related to morphological, ecological, and behavioral differences observed in the tortoise populations. Genetic evidence is only one factor among many that should be considered in managing desert tortoises (Crandall et al. 2000; DeSalle and Amato 2004; Green 2005). No direct evidence suggests that the mtDNA and microsatellite markers reflect the observed phenotypic differences and local adaptations, although the assumption is that identified genetic markers may serve as surrogates for these and other character traits (Pearman 2001). Behavioral differences between populations can be genetically linked, as in the case of garter snake food habits (Arnold 1981) and morphological variability in turtles can be heritable (Myers et al. 2006).

In the absence of data linking genotypic markers with specific phenotypic characters or adaptations in desert tortoises, we are confined to delineating recovery units based on available information, such as the differences in mtDNA and microsatellite markers described here, as well as differences in vegetative communities, physical attributes of the habitat, climate (e.g., mean number of freezing days annually, mean annual precipitation, amounts of precipitation occurring in summer), choice and availability of forage plants, cover sites (burrows, dens), and denning behavior.

The direct translation of molecular data into management units is subjective. On one extreme, it is possible to define 2 recovery units, based on the arbitrary subdivision of assignment values. However, the STRUCTURE analysis indicated the presence of at least 6 genetically cohesive units. Although this evaluation was compromised by multidimensional IBD, when we reduced the effects of IBD, 4 additional genetic units were identified in the Western Mojave Recovery Unit: sample groups 1–2, 3–5, 8, and 6–7 plus 9–10 (Fig. 4). Ultimately, the designation of recovery units must synthesize all relevant factors to achieve effective management.

Our analyses indicate that the Western Mojave Recovery Unit should be divided into 3 regions (western, southern, and central) and 3 corresponding recovery units: Western Mojave, Central Mojave, and Southern Mojave (Table 8, Fig. 7). Although the analysis by using STRUCTURE discovered 4 genetic units within the Western Mojave, the segregation of 1 site (8) would not facilitate effective management. Our proposed recovery units are similar to the 3 Desert Wildlife Management Areas described in the *Recovery Plan* and are concordant with the western, southern, and central regions of the Mojave Desert described by botanists and climatologists (Rowlands et al. 1982; Rowlands 1995a, 1995b). The western, central, and southern Mojave regions differ primarily in the amounts of summer rainfall, number of freezing days, and mean January minima and mean July maxima temperatures, as well as in species richness (vegetation) and types and composition of plant species with different metabolic pathways, e.g., C_3, C_4, and Crassulacean acid metabolism (CAM). The redefined Western Mojave Recovery Unit (Fig. 7) receives precipitation primarily in winter and $< 10\%$ of rainfall occurs in summer (Rowlands 1995a; Table 8). The summer flora is very limited, and tortoises rely heavily on the succulent green forbs and herbaceous perennial plants available in late winter and spring (Jennings 1993, 2002; Oftedal 2002; Oftedal et al. 2002). The proposed Central Mojave Recovery Unit is the hottest and driest of the 3 regions and is low in botanical diversity (Rowlands, 1995a). Of the 3 regions, the proposed Southern Mojave Recovery Unit has more summer precipitation and a higher richness of C_4 and CAM plant species (Rowlands 1995a). Until ca. 100 years ago, the Southern Mojave Recovery Unit was physically separated from the proposed Central Mojave and Western Mojave recovery units by the Mojave River; human activities have since reduced or eliminated the flow along much of the river.

Climatic differences between all recovery units profoundly affect timing and availability of forage, as well as seasonal activities and very possibly depth of burrows and, thus, protection from freezing temperatures and the hot, dry summers. The existing eastern recovery units in the Mojave population have higher percentages of precipitation in the summer, thus supporting a more diverse and complex summer flora (Table 8; Rowlands 1995a, 1995b; Oftedal 2002). A winter flora is also available. Differences in the mean number of freezing days per annum contribute to seasonal activity periods and the types of winter hibernacula protecting the tortoises from freezing. The Northern and Eastern Colorado Desert recovery units are the warmest, with 1–16 freezing days/y compared with 29–127 freezing days/y in the Mojave. Northeastern recovery units are by far the coldest, possibly contributing to the well-developed dens and lengthy tunnels on Beaver Dam Slope (Woodbury and Hardy1948) that are rarely observed outside the Northeastern Mojave and Upper Virgin River recovery units.

Genetic assignments do not support a separation between the Eastern Mojave and Northern Colorado recovery units, possibly because we only had 4 sample groups from these regions. The close geographic proximities of the sample groups (Fig. 7) are unlikely to reflect the potential diversity occurring along a 250 km north-south axis. Until more data are gathered along the north-south axis, we do not recommend treating the 2 recovery units as one, because of major differences in climate, forage availability, and seasonal activities. These distinctions may be exactly the kind of ecological/adaptive differences worthy of conservation management, independent of the units delimited by neutral molecular variation (Crandall et al. 2000; Allendorf and Luikart 2007). Significantly, unlike the genetically restricted and legally inapplicable ESU, the legal application of DPS allows for and promotes such protection (US Department of the Interior and US Department of Commerce 1996).

The Northeastern Recovery Unit (group 11) and the Upper Virgin River Recovery Unit (group 15) showed the strongest differentiation (MDS plot, assignment test, and unique matriarchal lineage). They may be more genetically isolated than other areas. Both potentially show evidence of recent population reductions. Additional sampling of these regions is encouraged for evaluation of current management strategies. Unfortunately, under current legislation these and perhaps other demes cannot be protected solely on the basis of the degree of threat alone, as recently advocated by Green (2005).

Recovery Actions. — Populations that have become disjunct or mixed as a result of recent anthropogenic activities may be suitable for restorative actions (Crandall et al. 2000; Allendorf and Luikart 2007). One restorative action would be to remove deliberately or inadvertently

Table 8. Physical and biological attributes of proposed recovery units for the Mojave population.

Recovery unit	Mean annual precipitation (mm)	% Rainfall June–Sept	Mean no. freezing days annually	Mean July maximum temperature (°C)	Topography	Vegetation types
Western Mojave	90–150	3.1–9.9	33–84	35.4–37.4	Flats, valleys, alluvial fans, rolling hills, mountainous slopes	(1) Creosote Bush Scrub, (2) Mojave Saltbush-Allscale Scrub (endemic), (3) Indian Rice Grass Scrub-Steppe, (4) Hopsage scrub, (5) Cheesebush scrub (west Mojave type)
Central Mojave	109	18.3–20.7	57 +	39.1–42.9	Flats, valleys, alluvial fans, rolling hills, mountainous slopes, rock outcrops, badlands, sand dunes, lava flows	(1) Creosote Bush Scrub, (2) Big Galleta Scrub Steppe, (3) Hopsage Scrub, (4) Cheesebush scrub, (4) Desert Psammophytes
Southern Mojave	108	18.1–36.1	29–104	37.2–39.1	Flats, valleys, alluvial fans, rolling hills, mountainous slopes, rock outcrops, lava flows	(1) Creosote Bush Scrub, (2) Big Galleta Scrub Steppe, (3) Hopsage Scrub, (4) Cheesebush scrub, (4) Desert Psammophytes, (5) Blackbush Scrub
Eastern Mojave	112–208	27.5–37.7	34 +	34.8–36.1	Flats, valleys, alluvial fans, bajadas, rocky slopes	(1) Big Galleta-Scrub Steppe, (2) Succulent Scrub (*Yucca*, *Opuntia*), (3) Creosote Bush Scrub, (4) Cheesebush Scrub (eastern Mojave type), (5) Indian Rice Grass Scrub-Steppe
Northeastern Mojave	100–210	27.1–41.0	46–127	38.2–40.1	Flats, valleys, alluvial fans, rocky slopes, deeply cut washes	(1) Creosote Bush Scrub, (2) Big Galleta Scrub-Steppe, (3) Desert Needlegrass Scrub-Steppe, (4) Blackbush Scrub
Upper Virgin River	210	28.7	96 +	38.4	Rocks, caves, sandstone crevices, sand dunes	Transitional Vegetation: (1) Sagebrush Scrub, (2) Psammophytes, Great Basin (sand sage), (3) Blackbush Scrub
Northern Colorado	112–129	32.6–34.1	2–12	42.2–42.3	Flats, valleys, bajadas, rocky slopes, small washes	(1) Succulent Scrub (*Fouquieria, Opuntia*, *Yucca*), (2) Blue Palo Verde-Smoke Tree Woodland, (3) Creosote Bush Scrub (lava flows)
Eastern Colorado	96–100	32.3–34.4	1–16	40.5–42.2	Flats, valleys, alluvial fans, small washes, deeply dissected washes, rocky slopes	(1) Succulent Scrub (*Fouqueria, Opuntia, Yucca*), (2) Blue Palo Verde-Ironwood-Smoke Tree Woodland, (3) Creosote Bush Scrub (rocky slopes)

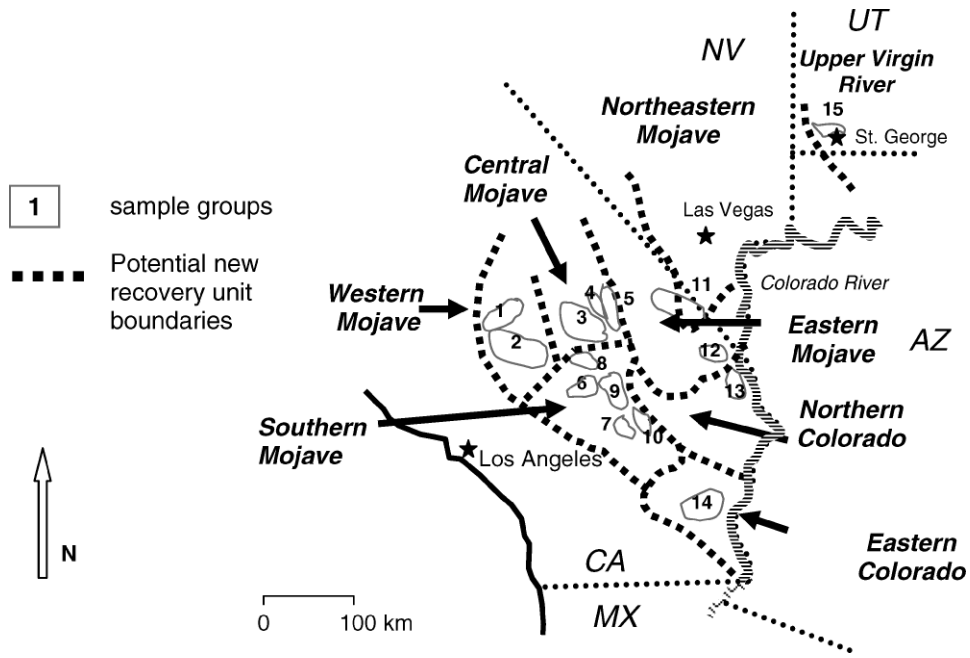

Figure 7. Sample groups of desert tortoises, *Gopherus agassizii*, shown with a new, preliminary alignment of recovery unit boundaries developed by using the mitochondrial deoxyribonucleic acid and microsatellite data presented in this study.

translocated tortoises from critical habitat. This strategy would be unreasonably difficult where populations are dense but may be a viable option where the area of interest and densities are limited, populations are declining, and most tortoises could be located and sampled. This strategy might be appropriate in the Upper Virgin River Recovery Unit and the Beaver Dam Slope Desert Wildlife Management Area (within the Northeastern Mojave Recovery Unit). Another restorative action would be to genetically test tortoises in the vicinity of frequently used recreation sites within national parks, research natural areas, and other protected areas: sites where visitors often release tortoises illegally, e.g., the Desert Tortoise Research Natural Area. The released tortoises from other populations could be identified and removed to a more appropriate place. In populations that have dropped below viable levels (e.g., Fremont-Kramer Desert Wildlife Management Area, Western Mojave Recovery Unit), informed and carefully planned augmentations or translocations could promote recovery, as has been done for a few other species (Allendorf and Luikart 2007). However, genetic planning is an essential part of such recovery efforts. Using tortoises within a well-defined recovery unit or local geographic area for headstarting or augmentation is far more desirable than translocating tortoises between recovery units. If local adaptations exist, then uninformed translocations of desert tortoises may do much more harm than good by introducing maladaptive genes into a locally adapted population.

Empirical studies need to be designed and tested to determine whether marker loci reflect specific adaptations with potential conservation value. For the Mojave population of the desert tortoise, the initial recovery units were defined on the basis of morphological, ecological, and behavioral differentiation, and the patterns of genetic variation parallel the earlier assessment in the *Recovery Plan*. Taken together, these 2 independent approaches strongly suggest the occurrence of local adaptation and evolutionary potential. Not only is it essential that this potential be conserved but also that underlying hypotheses be tested in the near future.

ACKNOWLEDGMENTS

We thank the Arizona Research Laboratories and staff at the Genomic Analysis and Technology Core for technical assistance, particularly M. Kaplan and H.-W. Herrmann. Samples from Arizona were contributed by C. Jones (University of Arizona) and D. Reidle (Arizona Game and Fish Department). At the Royal Ontario Museum, A. Lathrop, A. Ngo, and R. MacCulloch were helpful, and from California, A. Demmon was invaluable in processing samples. B.L. Burge and R.J. Turner provided historical data. K. Anderson, T. Bailey, R. Evans, R. Woodard, P. Woodman, P. Frank, B. Henen, and K. Nagy assisted by collecting samples. Valuable review comments were provided by D. Garrigan, K. Phillips, A. Russell, H.B. Shaffer, J.W. Sites, Jr., and J. Yee. A. Lathrop assisted with preparation of some figures and with GenBank submissions. Tissue samples were collected under federal and state permits to K.H. Berry (1994–2005), to K. Nagy for samples taken in the vicinity of Edwards Air Force Base, and to the late D.J. Morafka for samples along the southeastern boundary of Ft. Irwin. Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply

endorsement by the US government. We are grateful for the financial support of the US Air Force, and Natural Sciences and Engineering Research Council (Discovery Grant 3148) to R.W. Murphy, and to the US Geological Survey, Bureau of Land Management, Department of the Army (National Training Center, Ft. Irwin, California), Marine Corps Air Ground Combat Center at Twentynine Palms, California and the California Department of Fish and Game to K.H. Berry.

LITERATURE CITED

AKAIKE, H. 1974. A new look at the statistical model identification. Institute of Electrical and Electronics Engineers Transactions on Automatic Control 19:716–723.

AKAIKE, H. 1979. A Bayesian extension of the minimum AIC procedure of autoregressive model fitting. Biometrika 66: 237–242.

ALLENDORF, F.W. AND LUIKART, G. 2007. Conservation and the Genetics of Populations. Malden, MA: Blackwell Publishing. 642 pp.

ARÉVALO, E., DAVIS, S.K., AND SITES, J.W., JR. 1994. Mitochondrial DNA sequence divergence and phylogenetic relationships among eight chromosome races of the *Sceloporus grammicus* complex (Phrynosomatidae) in central Mexico. Systematic Biology 43:387–418.

ARNOLD, S.J. 1981. Behavioral variation in natural populations. II. The inheritance of a feeding response in crosses between geographic races of the garter snake, *Thamnophis elegans*. Evolution 35:510–515.

AVERILL-MURRAY, R.C. 2000. Survey protocol for Sonoran desert tortoise monitoring plots: reviewed and revised. Phoenix: Arizona Interagency Desert Tortoise Team and Arizona Game and Fish Department, 41 pp.

AVERILL-MURRAY, R.C. 2002. Reproduction of *Gopherus agassizii* in the Sonoran Desert, Arizona. Chelonian Conservation and Biology 4:295–301.

AVERILL-MURRAY, R.C., MARTIN, B.E., BAILEY, S.J., AND WIRT, E.B. 2002a. Activity and behavior of the Sonoran desert tortoise in Arizona. In: Van Devender, T.R. (Ed.), The Sonoran Desert Tortoise, Natural History, Biology, and Conservation. Tucson, AZ: University of Arizona Press and the Arizona-Sonora Desert Museum, pp. 135–158.

AVERILL-MURRAY, R.C., WOODMAN, A.P., AND HOWLAND, J.M. 2002b. Population ecology of the Sonoran desert tortoise. In: Van Devender, T.R. (Ed.), The Sonoran Desert Tortoise: Natural History, Biology, and Conservation. Tucson, AZ: The University of Arizona Press and the Arizona-Sonora Desert Museum, pp. 109–134.

BANKS, M.A. AND EICHERT, W. 2000. WHICHRUN (version 3.2): a computer program for population assignment of individuals based on multilocus genotype data. Journal of Heredity 91: 87–89.

BENSON, L. AND DARROW, R.A. 1981. Trees and Shrubs of the Southwestern Deserts. Third edition. Tucson, AZ: The University of Arizona Press, 416 pp.

BERRY, K.H. 1984. The distribution and abundance of the desert tortoise in California from the 1920s to the 1960s and a comparison with the current situation. In: Berry, K.H. (Ed.). The Status of the Desert Tortoise (*Gopherus agassizii*) in the United States. Report to the US Fish and Wildlife Service from the Desert Tortoise Council on Order No. 11310-0083–81, pp. 4-1–4-36.

BERRY, K.H. 1997. The Desert Tortoise Recovery Plan: an ambitious effort to conserve biodiversity in the Mojave and Colorado deserts of the United States. In: Van Abbema, J. (Ed.). Proceedings: Conservation, Restoration, and Management of Tortoises and Turtles—An International Conference. 11–16 July 1993, New York: Turtle and Tortoise Society and WCS Turtle Recovery Program, pp. 430–440.

BERRY, K.H. AND CHRISTOPHER, M.M. 2001. Guidelines for the field evaluation of desert tortoise health and disease. Journal of Wildlife Diseases 37:427–450.

BERRY, K.H. AND DUCK, T. 2006. Answering questions about desert tortoises. A guide to people who work with the public. www.deserttortoise.org/answeringquestions/html (7 January 2006).

BERRY, K.H. AND MEDICA, P. 1995. Desert tortoises in the Mojave and Colorado deserts. In: LaRoe, E.T., Farris, G.S., Puckett, C.E., Doran, P.D., and Mac, M.J. (Eds.). Our Living Resources: A Report to the Nation on the Distribution, Abundance, and Health of US Plants, Animals, and Ecosystems. Washington, DC: US Department of the Interior, National Biological Service, pp. 135–137.

BERRY, K.H., MORAFKA, D.J., AND MURPHY, R.W. 2002. Defining the desert tortoise(s): our first priority for a coherent conservation strategy. Chelonian Conservation and Biology 4:249–262.

BREMER, K. 1994. Branch support and tree stability. Cladistics 10: 295–304.

BRITTEN, H.B., RIDDLE, B.R., BRUSSARD, P.F., MARLOW, R.W., AND LEE, T.E., JR. 1997. Genetic delineation of management units for the desert tortoise, *Gopherus agassizii*, in northeastern Mojave Desert. Copeia 1997:523–530.

BROWN, M.B., BERRY, K.H., SCHUMACHER, I.M., NAGY, K.A., CHRISTOPHER, M.M., AND KLEIN, P.A. 1999. Seroepidemiology of upper respiratory tract disease in the desert tortoise in the western Mojave Desert of California. Journal of Wildlife Diseases 35:716–727.

BUCKLEY, T.R., ARENSBURGER, P., SIMON, C., AND CHAMBERS, G.K. 2002. Combined data, Bayesian phylogenetics, and the origin of the New Zealand cicada genera. Systematic Entomology 51: 4–18.

BURGE, B.L. 1977. Daily and seasonal behavior, and areas utilized by the desert tortoise *Gopherus agassizii* in southern Nevada. Proceedings of the Desert Tortoise Council Symposium 1977: 59–94.

CALIFORNIA CODE OF REGULATIONS. TITLE 14 SUBDIVISION 3, CHAPTER 3 SECTION 670.5. SEE ALSO: CALIFORNIA DEPARTMENT OF FISH AND GAME. 2004. State and Federally Listed Endangered and Threatened Animals of California. http://www.dfg.ca.gov/enforcement/index.aspx (7 January 2006).

CHAPUIS, M.P. AND ESTOUP, A. 2007. Microsatellite null alleles and estimation of population differentiation. Molecular Biology and Evolution 24:621–631.

CHRISTOPHER, M.M., BERRY, K.H., HENEN, B.T., AND NAGY, K.A. 2003. Clinical disease and laboratory abnormalities in free-ranging desert tortoises in California (1990–1995). Journal of Wildlife Diseases 39:35–56.

CHRISTOPHER, M.M., BERRY, K.H., WALLIS, I.R., NAGY, K.A., HENEN, B.T., AND PETERSON, C.C. 1999. Reference intervals and physiologic alterations in hematologic and biochemical values of free-ranging desert tortoises in the Mojave Desert. Journal of Wildlife Diseases 35:212–238.

COFFEEN, M.P. 1984. Utah Division of Wildlife Resources: State Report—Utah. Proceedings of the Desert Tortoise Council Symposium 1984:30–31.

COFFEEN, M.P. 1985. State Report—Utah. Proceedings of the Desert Tortoise Council Symposium 1985:40–41.

COFFEEN, M.P. 1986. State Report–Utah–1985. Proceedings of the Desert Tortoise Council Symposium 1986:20–28.

CONNOR, M. AND KAUR, J. 2004. Observations and activities of the naturalist at the Desert Tortoise Research Natural Area, Kern County, California: March 12 through June 7, 2004. Report to the Desert Tortoise Preserve Committee, Riverside, CA, in cooperation with the US Bureau of Land Management, Ridgecrest, CA.

COOK, J. 1983. Rehabilitation of the desert tortoise *Gopherus agassizii*. M.S. Thesis. California State Polytechnic University, Pomona, CA.

COOK, J., WEBER, A., AND STEWART, G. 1978. Survival of captive tortoises released in California. Proceedings of the Desert Tortoise Council Symposium 1978:130–135.

CORN, P.S. 1991. Displacement of desert tortoises: Overview of a study at the Apex heavy industrial use zone, Clark County, Nevada. Proceedings of the Desert Tortoise Council Symposium 1987–1991:295–303.

CORNUET, J.M. AND LUIKART, G. 1996. Description and power analysis of two tests for detecting recent population bottlenecks from allele frequency data. Genetics 144:2001–2014.

CRANDALL, K.A., BININDA-EMONDS, O.R.P., MACE, G.M., AND WAYNE, R.K. 2000. Considering evolutionary processes in conservation biology. Trends in Ecology and Evolution 15: 290–295.

DANKIN, E.E. AND AVISE, J.C. 2004. Microsatellite null alleles in parentage analysis. Heredity 93:504–509.

DESALLE, R. AND AMATO, G. 2004. The expansion of conservation genetics. Nature Reviews Genetics 5:702–712.

DINERSTEIN, E. AND MCCRACKEN, G.F. 1990. Endangered greater one-horned rhinoceros carry high levels of genetic variation. Conservation Biology 4:417–422.

EDWARDS, T. 2003. Desert tortoise conservation genetics. M.S. Thesis, University of Arizona, Tucson, AZ.

EDWARDS, T., GOLDBERG, C.S., KAPLAN, M.E., SCHWALBE, C.R., AND SWANN, D.E. 2003. PCR primers for microsatellite loci in the desert tortoise (*Gopherus agassizii*, Testudinidae). Molecular Ecology Notes 3:589–591.

EDWARDS, T., SCHWALBE, C.R., SWANN, D.E., AND GOLDBERG, C.S. 2004. Implications of anthropogenic landscape change on inter-population movements of the desert tortoise (*Gopherus agassizii*). Conservation Genetics 5:485–499.

ERNISSE, D.J. AND KLUGE, A.G. 1993. Taxonomic congruence versus total evidence, and amniote phylogeny inferred from fossils, molecules, and morphology. Molecular Biology and Evolution 10:1170–1195.

ESTOUP, A., JARNE, P., AND CORNUET, J.M. 2002. . Homoplasy and mutation model at microsatellite loci and their consequences for population genetics analysis. Molecular Ecology 11: 1591–1604.

FALUSH, D., STEPHENS, M., AND PRITCHARD, J.K. 2003. Inference of population structure: extensions to linked loci and correlated allele frequencies. Genetics 164:1567–1587.

FELSENSTEIN, J. 1985. Confidence limits on phylogenies: an approach using the bootstrap. Evolution 39:783–791.

FIELD, K.J. 1999. Translocation as a conservation tool applied to the desert tortoise: effects of the pre-release availability of water. Masters Thesis. University of Nevada, Reno.

FITZSIMMONS, N.N., MORITZ, C., AND MOORE, S.S. 1995. Conservation and dynamics of microsatellite loci over 300 million years of marine turtle evolution. Molecular Biology and Evolution 12:432–440.

FRASER, D.J. AND BERNATCHEZ, L. 2001. Adaptive evolutionary conservation, towards a unified concept for defining conservation units. Molecular Ecology 10:2741–2752.

FRIDELL, R.A. AND COFFEEN, M.P. 1993. Desert tortoise population on the Woodbury-Hardy monitoring plot, Beaver Dam Slope, 1986. Publication No. 93–06. Utah Division of Wildlife Resources, Salt Lake City.

FRITTS, T.H. AND JENNINGS, R.D. 1994. Distribution, habitat use, and status of the desert tortoise in Mexico. In: Bury, R.B. and Germano, D.J. (Eds.), Biology of North American Tortoises. Fish and Wildlife Research Report No. 13. Washington, DC: US Department of the Interior, National Biological Survey, pp. 49–56.

GARNIER-GERE, J. AND DILLMANN, C. 1992. A computer program for testing pairwise linkage disequilibria in subdivided populations. Journal of Heredity 86:248–249.

GARRIGAN, D. AND HEDRICK, P.W. 2003. Perspective: detecting adaptive molecular polymorphism, lessons from the MHC. Evolution 57:1707–1722.

GARZA, J.C. AND WILLIAMSON, E.G. 2001. Detection of reduction in population size using data from microsatellite loci. Molecular Ecology 10:305–318.

GERMANO, D.J. 1993. Shell morphology of North American tortoises. American Midland Naturalist 129:319–335.

GINN, S.W. 1990. Observations and activities of the naturalist for the Desert Tortoise Natural Area, Kern County, California: 18 March–2 June 1990. Report to the Desert Tortoise Preserve Committee, Ridgecrest, CA, and the US Bureau of Land Management, Riverside, CA.

GOLDBERG, C.S., KAPLAN, M.E., AND SCHWALBE, C.R. 2003. From the frog's mouth: buccal swabs for collection of DNA from amphibians. Herpetological Review 34:220–221.

GOLDBERG, T.L., GRANT, E.C., INENDINO, K.R., KASSLER, T.W., CLAUSSEN, J.E., AND PHILIPP, D.P. 2005. Increased infectious disease susceptibility resulting from outbreeding depression. Conservation Biology 19:455–462.

GOLDMAN, N. 1993. Statistical tests of models of DNA substitution. Journal of Molecular Evolution 36:182–198.

GOUDET, J., RAYMOND, M., DE MEEÜS, T., AND ROUSSET, F. 1996. Testing differentiation in diploid populations. Genetics 144: 1933–1940.

GREEN, D.M. 2005. Designatable units for status assessment of endangered species. Conservation Biology 19:1813–1820.

GUO, S.W. AND THOMPSON, E.A. 1992. Performing the exact test of Hardy-Weinberg proportions for multiple alleles. Biometrics 48:361–372.

HARDY, R. 1945. The influence of types of soils upon the local distribution of some mammals in southwestern Utah. Ecological Monographs 15:71–108.

HENEN, B.T., PETERSON, C.D., WALLIS, I.R., BERRY, K.H., AND NAGY, K.A. 1997. Effects of climatic variation on field metabolism and water relations of desert tortoises. Oecologia 117:365–373.

HOWLAND, J. 1989. Observations and activities of the naturalist for the Desert Tortoise Natural Area, Kern County, California: 12 March–12 July 1989. Report to the Desert Tortoise Preserve Committee, Ridgecrest, CA, and the US Bureau of Land Management, Riverside, CA.

HUELSENBECK, J.P. AND BOLLBACK, J.P. 2001. Application of the likelihood function in phylogenetic analysis. In: Balding, D.J., Bishop, M., and Cannings, C. (Eds.). Handbook of Statistical Genetics. New York: John Wiley and Sons, pp. 415–439.

HUELSENBECK, J.P. AND RONQUIST, F.R. 2001. MRBAYES: Bayesian inference of phylogenetic trees. Bioinformatics 17: 754–755.

JAEGER, E.C. 1950. Our Desert Neighbors. Stanford, CA: Stanford University Press, 239 pp.

JAEGER, E.C. 1955. Hard-shelled denizens of the wastelands. Desert Magazine 18(5):19–24.

JAEGER, E.C. 1957. (reprinted 1967). The North American Deserts. Stanford, CA: Stanford University Press, 308 pp.

JENNINGS, B. 1991. Observations and activities of the naturalists for the Desert Tortoise Natural Area, Kern County, California: 2 March—27 May 1991. Report to the Desert Tortoise Preserve Committee, Ridgecrest, CA, and the Bureau of Land Management, Riverside, CA.

JENNINGS, W.B. 1993. Foraging ecology of the desert tortoise (*Gopherus agassizii*) in the western Mojave Desert. M.Sc. Thesis, University of Texas at Arlington, Texas.

JENNINGS, W.B. 2002. Diet selection by the desert tortoise in relation to the flowering phenology of ephemeral plants. Chelonian Conservation and Biology 4:353–358.

KELLY, I. No date. Notebook of the Las Vegas Band, Southern Paiute. (Manuscript). Berkeley, CA: University of California Archives 38 2M, Anthropology Document 18, p. 89.

KIMURA, M. AND WEISS, G.H. 1964. The stepping stone model of population structure and the decrease of genetic correlation with distance. Genetics 49:561–576.

KLUGE, A.G. 1989. A concern for evidence and a phylogenetic hypothesis of relationships among *Epicrates* (Boidae, Serpentes). Systematic Zoology 38:7–25.

KRUSKAL, J.B. AND WISH, M. 1978. Multidimensional scaling. Beverly Hills, CA: Sage Publications, 96 pp.

LAMB, T. AND LYDEARD, C. 1994. A molecular phylogeny of the gopher tortoises, with comments on familial relationships within the Testudinoidea. Molecular Phylogenetics and Evolution 3:283–291.

LAMB, T. AND MCLUCKIE, A.M. 2002. Genetic differences among races of the desert tortoise. In: Van Devender, T.R. (Ed.). The Sonoran Desert Tortoise: Natural History, Biology, and Conservation. Tucson, AZ: The University of Arizona Press and the Arizona-Sonora Desert Museum, pp. 67–85.

LAMB, T., AVISE, J.C., AND GIBBONS, J.W. 1989. Phylogeographic patterns in mitochondrial DNA of the desert tortoise (*Xerobates agassizii*), and evolutionary relationships among the North American gopher tortoises. Evolution 43:76–87.

MANEL, S., GAGGIOTTI, O.E., AND WAPLES, R.S. 2005. Assignment methods, matching biological questions with appropriate techniques. Trends in Ecology and Evolution 20:136–142.

MCLUCKIE, A.M. AND FRIDELL, R.A. 2002. Reproduction in a desert tortoise (*Gopherus agassizii*) population on the Beaver Dam Slope, Washington County, Utah. Chelonian Conservation and Biology 4:288–294.

MCLUCKIE, A.M., BENNION, M.R.M., AND FRIDELL, R.A. 2004. Regional desert tortoise monitoring in the Red Cliffs Desert Reserve, 2003. Publication No. 04–21, Utah Division of Wildlife Resources, Salt Lake City, 61 pp.

MCLUCKIE, A.M., LAMB, T., SCHWALBE, C.R., AND MCCORD, R.D. 1999. Genetic and morphometric assessment of an unusual tortoise (*Gopherus agassizii*) population in the Black Mountains of Arizona. Journal of Herpetology 33:36–44.

MINDEN, R.L. 1980. Investigations of the desert tortoise (*Gopherus agassizii*) on the Beaver Dam Slope, Washington County, Utah. Publication No. 80–21. Utah State Division of Wildlife Resources, Salt Lake City, 43 pp.

MINDEN, R.L. AND KELLER, S.M. 1981. Population analysis of the desert tortoise (*Gopherus agassizii*) on the Beaver Dam Slope, Washington Co., Utah. Publication No. 81–14, Utah Division of Wildlife Resources, Salt Lake City, 49 pp.

MORITZ, C. 2002. Strategies to protect biological diversity and the evolutionary processes that sustain it. Systematic Biology 51: 238–254.

MYERS, E.M., JANZEN, F.J., ADAMS, D.C., AND TUCKER, J.K. 2006. Quantitative genetics of plastron shape in slider turtles (*Trachemys scripta*). Evolution 60:563–572.

NUSSEAR, K.E. 2004. Mechanistic investigation of the distributional limits of the desert tortoise *Gopherus agassizii*. Ph.D. Dissertation. University of Nevada, Reno.

NYLANDER, J.A.A. 2004. MrModeltest v2. Program distributed by author. Evolutionary Biology Centre, Uppsala University, Uppsala, Sweden.

NYLANDER, J.A.A., RONQUIST, F., HUELSENBECK, J.P., AND NIEVES-ALDREY, J.L. 2004. Bayesian phylogenetic analysis of combined data. Systematic Biology 53:47–67.

OFTEDAL, O.T. 2002. Nutritional ecology of the desert tortoise in the Mohave and Sonoran Deserts. In: Van Devender, T.R. (Ed.). The Sonoran Desert Tortoise. Natural History, Biology, and Conservation. Tucson, AZ: University of Arizona Press and the Arizona-Sonora Desert Museum, pp. 194–241.

OFTEDAL, O.T., HILLARD, S., AND MORAFKA, D.J. 2002. Selective spring foraging by juvenile desert tortoises (*Gopherus agassizii*) in the Mojave Desert: evidence of an adaptive nutritional strategy. Chelonian Conservation and Biology 4: 341–352.

PALMER, K.S., ROSTAL, D.C., GRUMBLES, J.S., AND MULVEY, M. 1998. Long-term sperm storage in the desert tortoise (*Gopherus agassizii*). Copeia 1998:702–705.

PEARMAN, P.B. 2001. Conservation value of independently evolving units, sacred cow or testable hypothesis? Conservation Biology 15:780–783.

PEARSE, D.E. AND CRANDALL, K.A. 2004. Beyond F_{ST}: population genetic analysis for conservation. Conservation Genetics 5: 585–602.

PIRY, S., LUIKART, G., AND CORNUET, J.M. 1999. BOTTLENECK: a computer program for detecting recent reductions in effective population size using allele frequency data. Journal of Heredity 90:502–503.

PRITCHARD, J.K., STEPHENS, M., AND DONNELLY, P. 2000. Inference to population structure using multilocus genotype data. Genetics 155:945–959.

RAYMOND, M. AND ROUSSET, F. 1995. GENEPOP (version 1.2): population genetics software for exact tests and ecumenicism. Journal of Heredity 86:248–249.

RONQUIST, F. 2004. Bayesian inference of character evolution. Trends in Ecology and Evolution 19:475–481.

ROWLANDS, P.G. 1995a. Regional bioclimatology of the California desert. In: Rowlands, P.G. and Latting, J. (Eds.). The California Desert: An Introduction to Natural Resources and Man's Impact. Volume 1. June Latting Books, pp. 95–134.

ROWLANDS, P.G. 1995b. Vegetational attributes of the California Desert Conservation Area. In: Rowlands, P.G. and Latting, J. (Eds.). The California Desert: An Introduction to Natural Resources and Man's Impact. Volume 1. June Latting Books, pp. 135–212.

ROWLANDS, P., JOHNSON, H., RITTER, E., AND ENDO, A. 1982. The Mojave Desert. In Bender, G.L. (Ed.). Reference Handbook on the Deserts of North America. Westport, CT: Greenwood Press, pp. 103–162.

RYDER, O.A. 1986. Species conservation and systematics: the dilemma of subspecies. Trends in Ecology and Evolution 1: 9–10.

SCHNEIDER, J.S. AND EVERSON, G.D. 1989. The desert tortoise (*Xerobates agassizii*) in the prehistory of the southwestern Great Basin. Journal of California and Great Basin Anthropology 11:175–202.

SCHNEIDER, S., ROESSLI, D., AND EXCOFFIER, L. 2000. ARLEQUIN, version 2.000: A software program for population genetics data analysis. Geneva, Switzerland: Genetics and Biometry Laboratory.

SCHWARTZ, T.S., OSENTOSKI, M., LAMB, T., AND KARL, S.A. 2003. Microsatellite loci for the North American tortoises (genus *Gopherus*) and their applicability to other turtle species. Molecular Ecology Notes 3:283–286.

SLATKIN, M. 1995. A measure of population subdivision based on microsatellite allele frequencies. Genetics 139:457–462.

SLATKIN, M. AND MADDISON, W.P. 1990. Detecting isolation by distance using phylogenies of genes. Genetics 126:249–260.

SPENCER, C.C., NEIGEL, J.E., AND LEBERG, P.L. 2000. Experimental evaluation of the usefulness of microsatellite DNA for detecting demographic bottlenecks. Molecular Ecology 9: 1517–1528.

STEBBINS, R.C. 2003. A Field Guide to Western Reptiles and Amphibians. Third Edition. New York: Houghton Mifflin, 533 pp.

SUGG, D.W. AND CHESSER, R.K. 1994. Effective population sizes with multiple paternity. Genetics 137:1147–1155.

SWOFFORD, D.L. 2002. Phylogenetic Analysis Using Parsimony. Sunderland, MA: Sinauer Associates Inc, software.

TURNER, F.B., HAYDEN, P., BURGE, B.L., AND ROBERSON, J.B. 1986. Egg production by the desert tortoise (*Gopherus agassizii*) in California. Herpetologica 42:93–104.

TURNER, R.M., BOWERS, J.E., AND BURGET, T.L. 1995. Sonoran Desert Plants: An Ecological Atlas. Tucson, AZ: University of Arizona Press, 504 pp.

US DEPARTMENT OF THE INTERIOR AND US DEPARTMENT OF COMMERCE. 1996. Policy regarding the recognition of distinct vertebrate population segments under the Endangered Species Act. Federal Register 61:4722–4725.

US FISH AND WILDLIFE SERVICE (USFWS). 1980. Endangered and threatened wildlife and plants: listing as threatened with critical habitat for the Beaver Dam Slope population of the desert tortoise in Utah. Federal Register 45:55654–55666.

US FISH AND WILDLIFE SERVICE (USFWS). 1990. Endangered and threatened status for the Mojave population of the desert tortoise. Federal Register 55:12178–12191.

US FISH AND WILDLIFE SERVICE (USFWS). 1994. Desert Tortoise (Mojave population) Recovery Plan. Portland, OR: US Fish and Wildlife Service, 73 pp. plus appendices.

WALLIS, I.R., HENEN, B.T., AND NAGY, K.A. 1999. Egg size and annual egg production by female desert tortoises (*Gopherus agassizii*): the importance of food abundance, body size, and date of egg shelling. Journal of Herpetology 33:394–408.

WAPLES, R.S. 1991. Pacific salmon, *Oncorhynchus* spp., and the definition of "species" under the Endangered Species Act. Marine Fisheries Review 53:11–22.

WAPLES, R.S. 1998. Evolutionarily significant units, distinct population segments, and The Endangered Species Act: Reply to Pennock and Dimmick. Conservation Biology 12:718–721.

WEBER, A.E., COOK, J.C., AND STEWART, G.R. 1979. A second report on survival in rehabilitated desert tortoises. Proceedings of the Desert Tortoise Council Symposium, 1979:101–103.

WEINSTEIN, M.N. AND BERRY, K.H. 1987. Morphometric analysis of desert tortoise populations. Report CA950-CT7–003. Riverside, CA: US Department of the Interior, Bureau of Land Management, 39 pp.

WEIR, B.S. AND COCKERHAM, C.C. 1984. Estimating F-statistics for the analysis of population structure. Evolution 38:1358–1370.

WHITLOCK, M.C. AND MCCAULEY, D.E. 1999. Indirect measures of gene flow and migration, $F_{ST} \neq 1/(4Nm + 1)$. Heredity 82: 117–125.

WOODBURY, A.M. AND HARDY, R. 1948. Studies of the desert tortoise, *Gopherus agassizii*. Ecological Monographs 18: 146–200.

Received: 11 February 2006
Revised and Accepted: 31 August 2007

THE SOUTHWESTERN NATURALIST 42(2):218–223 JUNE 1997

HABITAT RELATIONSHIPS OF THE COACHELLA VALLEY FRINGE-TOED LIZARD (*UMA INORNATA*)

CAMERON W. BARROWS

The Nature Conservancy, 53298 Avenida Montezuma La Quinta, CA 92253

ABSTRACT—The threatened Coachella Valley fringe-toed lizard (*Uma inornata*) is protected within a series of sand dune remnants. Understanding the specific habitat needs of these lizards is important to the management of this ecosystem. I examined habitat selection of *U. inornata* at both multiple isolated dunes and, more intensively, at a single dune site. For the multiple sites analysis, I found that habitat area and sand compaction were the most important features distinguishing between occupied and unoccupied dunes. At the single dune, I found sand compaction and the presence of plants such as *Dicoria canescens*, *Atriplex canescens*, and *Salsola tragus* to be associated with areas of high lizard use. The relative contribution of each of these variables differed with year, season, and age class of the lizards. In each year, including my multiple sites analysis, sand compaction was consistently the most important habitat characteristic I measured. *Uma inornata* were associated with locations on the dunes with deep, loose sand.

Fringe-toed lizards (*Uma* spp.) are restricted to aeolian sand habitats in the deserts of southwestern North America (Stebbins, 1944; Norris, 1958). In the Coachella Valley of southern California, limited distribution of aeolian environments, in conjunction with habitat loss due to regional dune stabilization and urbanization, has resulted in the listing of *U. inornata* as Threatened by the U.S. Fish and Wildlife Service in 1980. Subsequently, a preserve system has been established to conserve and maintain sand dune remnants. However, there are concerns about the long term viability of natural processes that maintain the aeolian habitat at one location in the preserve system (Barrows, 1996). Active management of sand dune habitat may ultimately be required to mimic the natural processes that would otherwise maintain this habitat. Consequently, an understanding of the habitat features important to these lizards is a necessary prerequisite to habitat manipulation.

Within aeolian habitat the distribution of *U. inornata* can be patchy (Turner et al., 1984). Previous studies have focused on the importance of sand grain size to lizard distribution within a site (Stebbins, 1944; Norris, 1958; Pough, 1970; Turner et al., 1984). Norris (1958) mentioned the potential importance of sand compaction and Turner et al. (1984) incorporated sand compaction, sand grain size, and surface coarseness into a regression model that explained 81% of the variation in lizard densities. I built on these previous studies by investigating further the importance of sand compaction and considering also the distribution and density of plants.

I examined habitat selection at two scales. At a coarse scale I measured the relationship of habitat variables to the presence or absence of lizards at multiple sites. At a much finer scale I investigated features that explained the distribution of lizards at a single site. Together these data provide evidence of the features that are important to the distribution of *U. inornata*.

MATERIALS AND METHODS—I collected all data within the Coachella Valley, Riverside County, California. In 1993, I surveyed 20 isolated aeolian sand drifts (sensu Norris, 1958) and dunes in the Indio Hills on the northern edge of the valley and on Garnet Hill at the western end. In addition I studied one of the largest of these sites in detail in 1994 and 1995.

At isolated dunes I compared habitat variables at sites occupied (n = 10) by *U. inornata* to those at unoccupied sites (n = 10). All variables were tested for normality with a Lilliefors test (Lilliefors, 1967), and when necessary, corrected with appropriate transformations. I used independent t-tests to identify significant differences between occupied and unoccupied sites. I then used discriminant functions

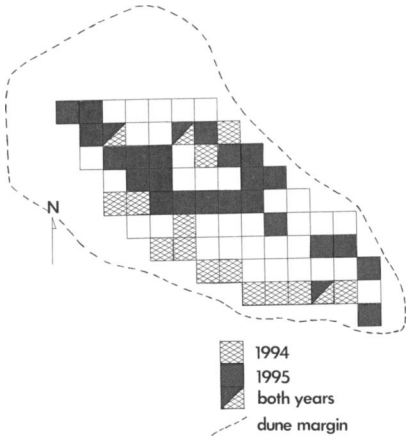

FIG. 1—Distribution of high use areas by *Uma inornata* in 1994 and 1995. High use is defined here as use within grid cells that exceeded the overall plot mean.

analysis to identify which habitat variables could be used to discriminate between occupied and unoccupied sites.

At all 20 sites I selected a random starting point and stretched a 30-m tape along the slope contour. I surveyed a single transect on sand drifts less than 7,000 m^2 and two transects on drifts larger than 7,000 m^2. I measured vegetative cover using a line-intercept method (Mueller-Dombois and Ellenberg, 1974). I recorded the intercept lengths of live shrubs to the nearest 0.01 m and used the percent cover of all live plant species, as well as open sand, to compare occupied with unoccupied dunes.

For substrate analyses, I measured sand compaction at five points chosen randomly along each transect by dropping a metal spike (150 g, 25 cm by 1 cm) from a height of 1 m and recording the mean penetration (to the nearest 0.5 cm) of five drops. I measured sand grain size distribution using a separation sieve on a 200 to 350-g sample from each transect.

To determine presence or absence of *U. inornata* I visited each site at optimal time and weather conditions: during May, June and July, between 0900 h and 1200 h, with temperatures (unshaded, 1 cm above sand) between 33°C and 43°C. To survey a sand patch I traversed the site systematically, tapping all vegetation to flush lizards. While conclusive proof of the lizard's absence is impossible, I considered them absent if none were located after five visits (about five man-hours).

At a single isolated dune I compared *U. inornata* distribution with the occurrence of plant and substrate types. I overlaid a grid of 73 cells, each 10 by 10 m, in the center of the 1.3-ha dune (Fig. 1). I mapped *U. inornata* sightings within the grid on 60 days in 1994 and 67 days in 1995. As with the multiple-site surveys, I visited all sites during optimal time and weather conditions to insure high lizard activity.

I sampled vegetation by counting individual plants of each species in each cell. The timing and quantity of precipitation differed between years; nearly three times as much rain fell in 1995 than in 1994 (11.2 versus 3.9 cm). I surveyed vegetation in May 1994 and in both May and August 1995, as vegetative cover changed substantially from spring to summer months.

I measured sand compaction within each cell in May 1994 and in both May and August 1995, as higher rainfall was accompanied by stronger winds, which changed the dune's topography during the sampling period. Since I measured sand grain size at this site in 1993, and found all measurements within the preferred ranges previously published for *U. inornata* (Stebbins, 1944; Norris, 1958; Pough, 1970), this variable was not measured in subsequent years.

To identify habitat features that characterize high use areas for *U. inornata*, I followed Rice et al. (1986), Rotenberry (1986) and Welsh and Lind (1995) in using a combined statistical approach to create a habitat model, allowing cross-validation between methods. In the first method, I used step-wise multiple regression to determine which variables significantly contributed to explaining the variance in lizard distribution. In the second method, I used discriminant functions analysis to identify which variables differentiate two groups of lizard use categories. Since I was interested in identifying variables associated with high use areas by the lizards, the two groups I contrasted were those cells with lizard occurrences at or below the overall grid mean (low use) and above the grid mean (high use). Prior to inclusion in the discriminant functions analysis, all variables were tested for normality (Lilliefors, 1967) and transformed if necessary. I used SYSTAT 5.0 (Wilkinson, 1990) for all statistics.

RESULTS—Descriptive statistics for variables used to distinguish between occupied and unoccupied isolated sand habitats are shown in Table 1. Only habitat area and sand compaction differed significantly. I used discriminant functions analysis to determine if these two variables in aggregate could distinguish between occupied and unoccupied sites. The distinction was significant (Wilks' Lambda = 0.44, $F = 10.96$, $d.f. = 2, 17$, $P = 0.001$) and correctly classified 18 of 20 sites as occupied or unoccupied.

In 1994 I recorded 369 adult and 61 hatch-

TABLE 1—Summary statistics and *t*-test results for habitat variables measured on 20 isolated patches of aeolian sand in 1993. Degrees of freedom for all *t*-tests = 18.

	Occupied sites (n = 10)			Unoccupied sites (n = 10)				
	Mean	1 *SD*	Range	Mean	1 *SD*	Range	t	P
Habitat patch size (m^2)	6,900	6,350	900–20,000	1,300	1,600	120–5,000	3.55	0.002
Sand compaction (cm)	11	3	8–15	8	3	5.5–14	3.37	0.003
Open sand (%)	71	6	61–78	68	14	48–86	1.13	0.272
Live shrubs (%)	12	7	6–29	11	9	0–30	−0.11	0.912
Modal sand grain size (mm)	0.250	0.078	0.180–0.355	0.355	0.051	0.250–0.355	−1.44	0.171

ling *U. inornata* locations on a single isolated dune; in 1995 I recorded 434 adult and 167 hatchling *U. inornata* there. Habitat variables were used in a step-wise multiple regression to determine their relative and aggregate importance in explaining the occurrence of *U. inornata* within this site (Table 2). Pairwise correlations between variables were examined; all of the variables used in the regression models were independent. In 1994 and in summer 1995, sand compaction was the leading variable in explaining adult lizard distribution, accounting for nearly 35% of the variance in 1994 and 25% in summer 1995. Habitat selection in 1995 increased in complexity with the addition of vegetation variables to the habitat model. In aggregate, these variables accounted for nearly 50% of the variance in adult lizard distribution. In spring 1995, adult lizards were associated with spring Russian thistle (*Salsola tragus*) and summer *Dicoria canescens*. Hatchling (young of the year) *U. inornata* in summer 1995 were associated with similar habitat features as were spring adults, even though most Russian thistles were dead when hatchlings first emerged in summer. Hatchlings associated negatively with living Russian thistle during summer months.

The discriminant functions analyses identified a similar, but not identical, set of habitat variables in creating a habitat model (Table 3). In 1994 the only difference from the step-wise multiple regression model was the addition of *Dicoria* as a feature that differentiated between high and low use areas for adult lizards. In spring 1995, none of the habitat variables I measured differentiated between high and low lizard use cells. In summer 1995, spring densities of *Salsola*, summer *Dicoria* densities and sand compaction separated high and low use

TABLE 2—Step-wise multiple regression models describing the contribution of habitat variables to explaining variances in *U. inornata* distribution on a single dune. Numerical values shown are correlation coefficients for variables after entry into the regression model. Numbers in parentheses are the order in which the variables were entered into the regression model. Coefficients shown in bold type are those variables which were also identified in the discriminant functions analysis procedure as associates of high lizard use areas.

Variable	Adults 1994	Hatchlings 1994	Adults 1995 (spring)	Adults 1995 (summer)	Hatchlings 1995
Atriplex (spring)	—	**0.302 (2)**	—	—	0.370 (3)
Dicoria (summer)	—	—	0.121 (2)	**0.242 (3)**	0.196 (2)
Salsola (spring)	—	—	0.052 (1)	—	**0.103 (1)**
Salsola (summer)	—	—	—	0.510 (2)	−0.258 (4)
Sand compaction	**0.348 (1)**	**0.154 (1)**	—	**2.065 (1)**	—
Multiple R^2	0.348	0.282	0.193	0.484	0.284
Probability (F test)	<0.001	0.001	0.001	<0.001	<0.001

TABLE 3—Single and multivariate probabilities for the contribution of habitat variables in discriminating between grid cells with high lizard use (above plot means) and low use (at or below the plot mean), using discriminant functions analysis. Probabilities shown in bold type are those variables also identified as explaining a significant amount of the variance in *U. inornata* densities in the stepwise multiple regression model.

Variable	Adults 1994	Hatchlings 1994	Adults 1995 (spring)	Adults 1995 (summer)	Hatchlings 1995
Atriplex (spring)	—	**0.010**	—	—	—
Dicoria (summer)	0.003	—	—	**0.001**	—
Salsola (spring)	—	—	—	0.013	**0.006**
Salsola (summer)	—	—	—	—	—
Sand compaction	**<0.001**	**0.002**	—	**0.001**	0.002
Wilks' lambda	0.600	0.786	0.862	0.542	0.800
F-statistic	<0.001	0.003	0.269	<0.001	0.061

areas for adult lizards. For hatchlings that year, spring Russian thistle densities and sand compaction discriminated between use groupings. Habitat attributes for cells with higher than average lizard use are shown in Table 4.

DISCUSSION—Within the landscape mosaic of aeolian sand there are large areas of suitable sand size where *U. inornata* is nonetheless patchy in distribution. Previous studies have indicated that these lizards require sand grains between 1.0 and 0.1 mm in diameter, with preferred modal sizes being: less than 0.5 mm (Stebbins, 1944); 0.375 mm to 0.11 mm (Norris, 1958); and 0.5 mm to 0.25 mm (Pough, 1970). All of the sites investigated in this study, occupied and unoccupied, had modal sand grain sizes within the range of those reported to be preferred by *U. inornata.* Since sand grain size alone did not explain the presence, absence, or abundance of *U. inornata* in aeolian habitats, other features also must contribute.

Results of the multiple-sites survey indicated that sand compaction and sand patch size were important habitat features for the lizards. The discriminant functions analysis correctly classified all but two of the 20 sites using those two variables. One of those classified incorrectly as occupied, when in fact it was not, was occupied by *U. inornata* in the 1980's (Allan Muth, pers. comm.), suggesting a recent extirpation. The coarse nature of my data prevented any conclusions about the importance of vegetative features.

At the single dune where I conducted more intensive investigations, the combined use of step-wise multiple regressions and discriminant analyses allowed me to validate variables within an *U. inornata* habitat model. Sand compaction, along with four-winged saltbush (*Atriplex*

TABLE 4—Habitat values for grid cells with high lizard use (above the overall plot average) for those variables that contributed significantly to discriminating between high and low *U. inornata* use areas using a discriminant functions analysis habitat model.

	Atriplex (Sp)			*Dicoria* (Su)			*Salsola* (Sp)			Sand compaction		
Variable	Mean (/m²)	1 *SD*	Range	Mean (/m²)	1 *SD*	Range	Mean (/m²)	1 *SD*	Range	Mean (cm)	1 *SD*	Range
Adults 1994	—	—	—	0.04	0.05	0.00–0.16	—	—	—	9.5	2.5	6.0–13.5
Hatchlings 1994	0.042	0.05	0.00–0.18	—	—	—	—	—	—	9.5	2.5	6.0–13.5
Adults 1995 (summer)	—	—	—	0.082	0.07	0.00–0.22	0.242	0.15	0.02–0.58	9.0	1.5	6.0–13.0
Hatchlings 1995	—	—	—	—	—	—	0.232	0.14	0.03–0.58	9.0	1.5	7.0–13.0

canescens), Russian thistle and *Dicoria* densities were confirmed as features that distinguished lizard high use areas in both statistical techniques. The relative contribution of each of these variables varied with year, season, and age class of the lizards.

In each year, including my multiple-sites analysis, sand compaction was consistently the most important habitat characteristic I measured. *Uma inornata* were associated with locations on the dunes with deep, loose sand. Turner et al. (1984) identified sand compaction as important to explaining differences in lizard densities among sites. Fringe-toed lizards bury in loose sand to escape predators and hot temperatures (Stebbins, 1944; Pough, 1970). Burying is insufficient to escape the highest summer temperatures at unshaded locations; by midday, lethal temperatures reach the depths at which *U. inornata* normally bury. Before the onset of lethal temperatures, buried lizards emerge and either enter rodent burrows, or sit or bury in the shade of dense shrubs (Pough, 1970).

Beyond providing shade for cooling, shrubs are an important food resource. I regularly observed *U. inornata* eating *Dicoria* leaves, gleaning arthropods from the foliage and excavating insect larvae from the plant base. Though not as often, I did see the lizards gleaning insects from Russian thistle leaves as well. Both of these plant species appeared to have much greater arthropod abundances than did perennial shrubs such as the saltbush. When annual plants were common, as in 1995, *U. inornata* were associated with areas of high *Dicoria* or Russian thistle densities. I believe there is a critical maximum density for these plants; above this density lizards avoid the area, but this avoidance was not observed here.

Russian thistle was the only non-native, invasive plant on my plot. Land managers have expressed concern that this species may have a negative impact on *Uma inornata*, and thus may need to be controlled. My data indicate that Russian thistle can be a positive component of fringe-toed lizard habitat. *Dicoria* (a native) and Russian thistle have a similar appearance and distribution when occurring on aeolian sands. Important differences do exist: Russian thistle is generally dead by mid summer and is not eaten by *U. inornata*; *Dicoria*, which they do eat, persists through late summer, and flower typically in October. Durtsche (1995) identified *Dicoria* as an important food plant for *U. inornata* in late summer and suggested that this plant's abundance may be related to *U. inornata* population trends.

The seasonal differences in plant associations between adult and hatchling *U. inornata* may be explained by differences in the lizards' risk of predation. In addition to all the same predation pressures the adults face, hatchlings are also subject to predation from adult lizards of several species, including their own (Allan Muth and Mark Fisher, pers. comm.). Hatchling *Uma* appear to seek dense vegetation for cover, whether or not it has abundant food resources, and the hatchlings avoid areas of high adult use such as live Russian thistles in late summer. Dead Russian thistle in summer, (characterized as spring *Salsola* in this report), as well as saltbush have low food resources but high cover.

These data in aggregate explain only a portion of the variance in adult lizard distribution in 1994 and 1995. Social interactions (breeding and antagonistic behaviors) may not be related to habitat features and thus may account for much of the unexplained variance. The lack of habitat correlates to lizard distribution in spring 1995 may reflect the relatively intense breeding activity occurring at that time. Temporary food resources also affect lizard distribution. For example, episodic mating swarms of small flies resulted in several individual lizards foraging together, away from their regular areas of occupancy. Although the swarms lasted from only a few hours to a few days, nevertheless they affected lizard distribution.

The associations described here should provide important information to land managers if habitat manipulation is necessary to manage aeolian habitat within the established preserve system. The site I studied intensively for two years is within the preserve where there are concerns about the viability of natural processes that maintain the habitat (Barrows, 1996). I believe it is representative of the area where habitat manipulation may be necessary.

I want to thank M. Fisher, S. Fox, K. Barrows and two anonymous reviewers for greatly improving all aspects of this paper.

Literature Cited

Barrows, C. W. 1996. An ecological model for the protection of a dune ecosystem. Conservation Biology 10:888–891.

Durtsche, D. D. 1995. Foraging ecology of the fringe-toed lizard, *Uma inornata*, during periods of high and low food abundance. Copeia 1995: 915–926.

Lilliefors, H. W. 1967. On the Kolmogorov-Smirnov test for normality with mean and variance unknown. Journal of the American Statistical Association 64:399–402.

Mueller-Dombois, D., and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley and Sons, New York.

Norris, K. S. 1958. The evolution and systematics of the iguanid genus *Uma* and its relation to the evolution of other North American desert reptiles. Bulletin of the American Museum of Natural History 114:251–326.

Pough, F. H. 1970. The burrowing ecology of the sand lizard *Uma notata*. Copeia 1970:145–157.

Rice, J. C., R. D. Ohmart, and B. W. Anderson. 1986. Limits in a data-rich model: modeling experience with habitat management on the Colorado River. Pp. 79–86, *in* Wildlife 2000: Modeling Habitat Relationships in Terrestrial Vertebrates (J. Verner, M. J. Morrison, and C. J. Ralph, eds.). Univ. Wisconsin Press, Madison, Wisconsin.

Rotenberry, J. T. 1986. Habitat models of shrub-steppe birds: even good models cannot predict the future. Pp. 217–221, *in* Wildlife 2000: Modeling Habitat Relationships in Terrestrial Vertebrates (J. Verner, M. J. Morrison, and C. J. Ralph, eds.). Univ. Wisconsin Press, Madison, Wisconsin.

Stebbins, R. C. 1944. Some aspects of the ecology of the iguanid genus *Uma*. Ecological Monographs 14:311–332.

Turner, F. B., D. C. Weaver, and J. C. Rorabaugh. 1984. Effects of reduction in windblown sand on the abundance of the fringe-toed lizard (*Uma inornata*) in the Coachella Valley, California. Copeia 1984:370–378.

Welsh, H. H., and A. J. Lind. 1995. Habitat correlates of the Del Norte salamander, *Plethodon elongatus*, (Caudata: Plethodontidae), in northwestern California. Journal of Herpetology 29:198–210.

Wilkinson, L. 1990. SYSTAT: the system for statistics. SYSTAT, Inc., Evanston, Illinois.

Exhibit 651

Vol. 12: 167–177, 2010
doi: 10.3354/esr00298

ENDANGERED SPECIES RESEARCH
Endang Species Res

Published online August 24

Contribution to the Theme Section 'Responses of animals to habitat alteration'

OPEN ACCESS

Effects of subsidized predators, resource variability, and human population density on desert tortoise populations in the Mojave Desert, USA

Todd C. Esque[1,*], Ken E. Nussear[1], K. Kristina Drake[1], Andrew D. Walde[2], Kristin H. Berry[3], Roy C. Averill-Murray[4], A. Peter Woodman[5], William I. Boarman[6], Phil A. Medica[1], Jeremy Mack[3,8], Jill S. Heaton[7]

[1]US Geological Survey, Western Ecological Research Center, 160 North Stephanie Street, Henderson, Nevada 89074, USA
[2]ITS - A QinetiQ North American Company, 8000 San Gregorio Rd., Atascadero, California 93422, USA
[3]US Geological Survey, Western Ecological Research Center, 22835 Calle San Juan de Los Lagos, Moreno Valley, California 92553, USA
[4]US Fish and Wildlife Service, Desert Tortoise Recovery Office, 1340 Financial Blvd, #234, Reno, Nevada 89502, USA
[5]Kiva Biological Consulting, PO Box 1210, Inyokern, California 93527, USA
[6]Conservation Science Research and Consulting, 2522 Ledgeview Place, Spring Valley, California 91977, USA
[7]Department of Geography, University of Nevada, Reno, 1664 N. Virginia Street, MS 154, Reno, Nevada 89557, USA
[8]*Present address:* Department of Zoology, Miami University, Oxford, Ohio 45056, USA

ABSTRACT: Understanding predator–prey relationships can be pivotal in the conservation of species. For 2 decades, desert tortoise *Gopherus agassizii* populations have declined, yet quantitative evidence regarding the causes of declines is scarce. In 2005, Ft. Irwin National Training Center, California, USA, implemented a translocation project including 2 yr of baseline monitoring of desert tortoises. Unusually high predation on tortoises was observed after translocation occurred. We conducted a retrospective analysis of predation and found that translocation did not affect the probability of predation: translocated, resident, and control tortoises all had similar levels of predation. However, predation rates were higher near human population concentrations, at lower elevation sites, and for smaller tortoises and females. Furthermore, high mortality rates were not limited to the National Training Center. In 2008, elevated mortality (as high as 43%) occurred throughout the listed range of the desert tortoise. Although no temporal prey base data are available for analysis from any of the study sites, we hypothesize that low population levels of typical coyote *Canis latrans* prey (i.e. jackrabbits *Lepus californicus* and other small animals) due to drought conditions influenced high predation rates in previous years. Predation may have been exacerbated in areas with high levels of subsidized predators. Many historical reports of increased predation, and our observation of a range-wide pattern, may indicate that high predation rates are more common than generally considered and may impact recovery of the desert tortoise throughout its range.

KEY WORDS: *Gopherus agassizii* · Coyote · Predation · Translocation · Mojave Desert · Prey

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INTRODUCTION

The desert tortoise *Gopherus agassizii* occurs over large portions of the Mojave and Sonoran Deserts of the southwestern United States and northwestern Mexico (Germano et al. 1994), and the Mojave population receives federal and state protection north and west of the Colorado River in Arizona, Utah, Nevada, and California (USFWS 1994). Numerous factors have been identified as threats to desert tortoise populations

*Email: todd_esque@usgs.gov

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(USFWS 1994), and these factors do not operate independently, but rather synergistically (Tracy et al. 2004, USFWS 2008). Growing human populations, for example, can create resource subsidies of food and water that together allow native predator densities to increase beyond normal population levels (Goodrich & Buskirk 1995), and predation is often identified as a problem in the management and recovery of at-risk species (Gompper & Vanak 2008), including desert tortoises (Woodbury & Hardy 1948, Turner et al. 1984, Berry 1986).

Although the list of predators of all age-classes of tortoises is substantial (Woodbury & Hardy 1948, Luckenbach 1982, Grover & DeFalco 1995), predation on adults is usually attributed to larger canids (i.e. coyotes *Canis latrans* and free-roaming dogs *Canis familiaris*) or mountain lions *Felis concolor* (Woodbury & Hardy 1948, Turner et al. 1984, Peterson 1994, Medica & Greger 2009); more recently, mortality of adults from common ravens *Corvus corax* has been observed (K. K. Drake pers. obs., D. Hinderle et al. pers. obs.). Coyote predation is the most frequently cited cause of predation on adult tortoises and has been reported to range from 18 to 30% annually during some research projects (Turner et al. 1984, Peterson 1994). It has been speculated that levels of coyote predation on tortoises are inversely related to the abundance of the preferred coyote prey base of small mammals such as rodents and lagomorphs (Woodbury & Hardy 1948, Reyes Osorio & Bury 1982, Turner et al. 1984); however, there has been no direct documentation of population levels of coyotes and their possible prey species for the Mojave Desert ecoregion.

The Ft. Irwin National Training Center (NTC) recently translocated 571 tortoises from the military reservation to nearby public lands (Esque et al. 2005, Heaton et al. 2008a). As part of a research program designed to provide information about the effects of translocation on desert tortoises, we monitored the health and ecology of desert tortoises beginning in May 2005. All tortoises in the study were monitored monthly for at least 1 yr prior to the translocation.

Translocation occurred between 27 March and 18 April 2008. Tortoises were translocated from US Department of Defense lands in the NTC Southern Expansion Area (Heaton et al. 2008a) to the Superior-Cronese Desert Wildlife Management Area (DWMA) of critical habitat, located in the western Mojave Desert immediately south of the NTC (Fig. 1). The tortoises were moved to 14 widely separated unfenced areas (~2.58 km^2) on public lands in a contiguous area of 1000 km^2. The translocated tortoises were released in groups of 10 to 50 ind. per release area on sites occupied by resident desert tortoises. As part of several independent, yet coordinated research projects, we studied 3 treatment groups of tortoises, including those that were translocated, animals that already lived in and around the release sites (residents), and tortoises found in intervening areas more distant from release sites (controls) which did not overlap with translocated animals and were thus not affected by translocation activities. By May 2008, losses of desert tortoises were occurring among all treatment groups in localized areas. Field observations (i.e. coyote tracks and bite or chew marks on the shells and limbs) at the scene of predatory events revealed that coyotes killed tortoises. There were also isolated incidents of attempted predation by common ravens on adult tortoises.

We analyzed local variation in the occurrence of mortality among the translocated, resident, and control groups of desert tortoises that we studied as part of the NTC desert tortoise translocation. We also analyzed the extent to which predation rates in the study area could have been related to other factors that could influence predator population levels. Factors of concern include: the distribution of human population density; the distance from urban areas; the number of dirt road segments per km^2; and physical factors of the landscape, such as elevation and surface roughness. Finally, we provide additional data documenting mortality rates for sites spanning the range of the desert tortoise in the Mojave Desert.

MATERIALS AND METHODS

Study area. The primary study area (~1000 km^2) was within the Superior-Cronese DWMA located within the Western Mojave Recovery Unit of Critical Habitat for desert tortoises (USFWS 1994, Heaton et al. 2008a, see Ft. Irwin, Fig. 1). The study area was characterized as typical Mojave Desert scrub vegetation (Turner 1994), ranging in perennial plant cover from 1 to 29%. Elevation ranged from 500 to 900 m. During the period of record (1943 to 2009), the long-term annual precipitation mean was 98.8 ± 6.6 (SE) mm for Barstow, California (Fig. 2). The lowest precipitation on record occurred in 2006 (19.1 mm), followed by 56% below normal in 2007, and slightly over 100% of the long-term mean in 2008 (106.1 mm).

Range-wide mortality data for desert tortoises came from study plots throughout the Mojave Desert (Fig. 1). Precipitation during the study period was above the long-term mean for several representative sites across the Mojave Desert, followed by 2 yr of below-average precipitation across the Mojave Desert and similar to the pattern observed for Barstow, California (Fig. 2).

Tortoise data. ***Ft. Irwin NTC translocation analysis:*** Upon first capture, all desert tortoises were measured, and radio-transmitters were attached directly onto the

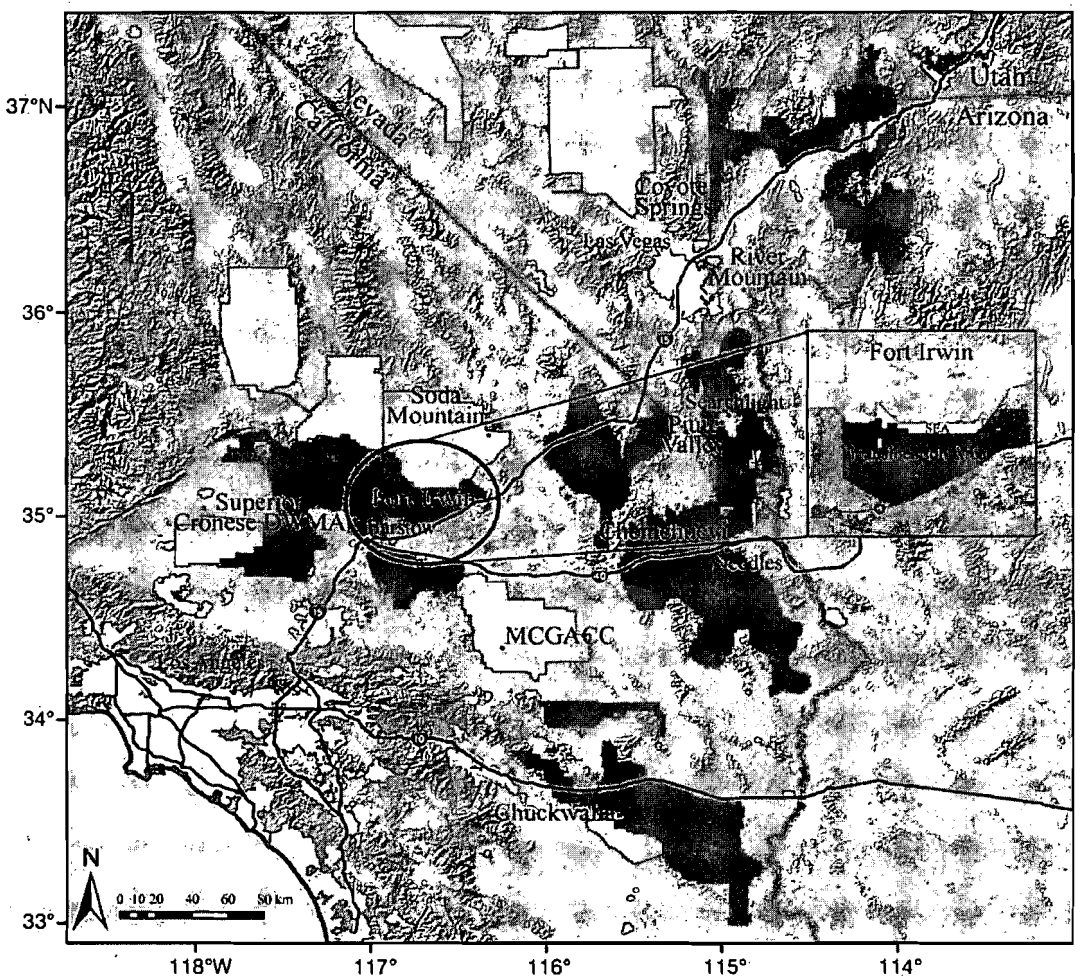

Fig. 1. Mojave Desert locations of desert tortoise study areas that were considered in comparisons of desert tortoise mortality. Desert tortoise critical habitat is represented by dark-gray polygons, US Department of Defense lands are represented as light gray polygons, and urban areas are shown in white. The Fort Irwin study site is represented by an oval (with zoomed inset), and range-wide sites are given as filled circles. DWMA: Desert Wildlife Management Area, MCGACC: Marine Corps Ground to Air Combat Center, SEA: southern expansion area. See Fig. 3 for more detail of the translocation area

carapace using epoxy (Boarman et al. 1998). Midline carapace length was used to represent body size. We used desert tortoise locality data from late March 2008 through December 2008 to analyze localized predation of desert tortoises within the Ft. Irwin NTC translocation study area. We analyzed records for 149 control, 140 resident, and 357 translocated desert tortoises (not all of the 571 translocated desert tortoises remained transmittered and part of the active research study). Desert tortoises in all 3 groups were monitored at least monthly (typically weekly) and were the subjects of several concurrent investigations on behavior, disease, spatial distribution, reproduction, and stress physiology. Based on these extremely detail-oriented studies, the condition of all the tortoises was monitored closely. The condition of each animal and any change in condition was noted and discussed among research teams such that overtly unhealthy or moribund animals were detected. For the purposes of this report, all other tortoises that were found dead, but had been healthy when last seen, were considered to be dead due to predation. Fifteen tortoises found to be overtly unhealthy with either clinical signs of disease or reduced mobility due to limb dysfunction were permanently removed from the study, as they were incorporated into pathology research. Four additional tortoises were removed from the study due to injuries including suspected canid-inflicted wounds or other injuries (e.g. snakebite) and not included in the analyses. Animals that were lost (e.g. due to transmitter failure) were also excluded from the analyses. While some of those animals may have died, we chose not to inflate mortality rates with speculative figures for which we had no further evidence.

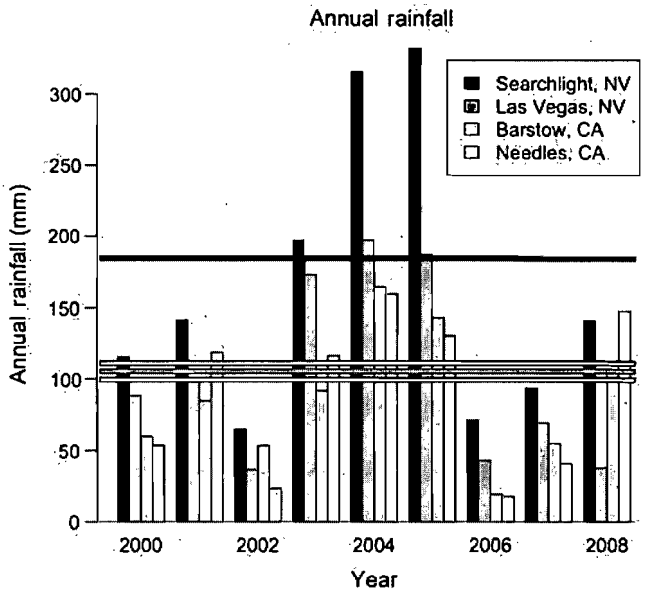

Fig. 2. Annual rainfall for Searchlight and Las Vegas, Nevada, and Barstow and Needles, California (sites near the Piute Valley, Coyote Springs Valley, Superior Cronese, and Chemehuevi Valley range-wide study sites, respectively) from 2000 to 2008 and including average precipitation of the entire record for each site (horizontal bars, same key as for site locations). Annual rainfall patterns throughout the Mojave were lower than average in 2006 and 2007

Regional mortality analysis: We used adult desert tortoise mortality data that were accumulated from 9 sites across the entire range of the Mojave Desert tortoise, excluding data from those previously described. These additional projects all represented sample populations of desert tortoises that were radio-tracked and allowed to range freely. Tortoises were monitored monthly in each of these studies, providing up-to-date information about their health status and general condition. All studies involving these tortoises were less invasive than the translocation project at Ft. Irwin, and consisted mainly of non-manipulative behavioral studies, although blood samples were collected from some individuals for health status evaluation. For example, 7 out of 9 of the sites were originally established for the sole purpose of observing typical animal behavior (USFWS 2006, Inman et al. 2009). One site in the River Mountains of Nevada included 19 translocated tortoises that were transmittered and not otherwise manipulated (USFWS unpubl. data), and the Soda Mountains site is a long-term study site used for a variety of observational research projects, including health status (Berry et al. 2006). Percent mortality was analyzed on a calendar-year basis by dividing the number of dead tortoises by the number of tortoises monitored that year multiplied by 100.

Spatial data layers. We included several covariates that represented perceived threats to desert tortoises, or hypothetical benefits to predators, that could aid in explaining mortality separately from possible translocation effects. We predicted that elevation and surface roughness would correlate with variability in predator or desert tortoise densities. We also predicted that proximity to urban areas, local human population density, and road density would correlate with additional direct and indirect anthropogenic influences, such as habitat degradation, subsidization of natural predators to elevated levels, and potential increases in free-roaming dog populations. We developed all spatial layers for the Ft. Irwin study area as raster layers in a geographic information system (GIS) with a 1 km^2 cell size. We calculated the elevation layer as the area-weighted average over the 1 km^2 cells from a 30 m digital elevation model (DEM). Surface roughness was calculated as the ratio of surface area to planar area for each grid cell. Thus, surface roughness is a coarse estimation of the landscape texture, such that the analysis roughly describes landforms such as hilliness and large arroyos, bajadas, and mountain slopes. We calculated distance to urban areas from the center of each grid cell to the edge of the nearest urban area polygon. Urban area polygons were acquired using the ESRI coverage for the US Census of Urbanized Areas (http://arcdata.esri.com/data/tiger2000/tiger_county.cfm?sfips=06). We derived the human population raster layer from 2000 US Census Block Centroid Populations (US Census Bureau 2000) data using a kernel density estimator. We calculated the kernel density for the 1 km^2 grids using a 15 km range. We used neighborhood statistics to sum the estimated population for a 15 km radius surrounding each cell in the analysis to obtain an estimate of the local human population likely to influence habitat at a 1 km scale.

We imported 1 location for each desert tortoise at the time of translocation, or where predation occurred for desert tortoises found dead, into a GIS, and intercepted the points with the raster layers described above. We analyzed the status (alive or dead) for desert tortoises using a logistic general linear model where sex and treatment group (i.e. translocated, resident, and control) were included as factors, and desert tortoise size, elevation, surface roughness, distance to urban areas, road density, and the human population level for the area were included as covariates using the glm function R 2.9.2 (R Development Core Team 2009). We selected among potential models including different combinations of factors and covariates that described the likelihood of mortality by using model performance, as measured by Akaike's information criterion corrected for small sample sizes (AICc), for ranking potential models. We considered a 2-point

improvement of AICc (where a smaller value is better; Burnham & Anderson 2002) as an indication of a better performing model. We also compared models and estimated the relative importance of different parameters based on normalized Akaike weights (w_i; Burnham & Anderson 2002) and the model deviance (Anderson 2008). We analyzed contrasts among treatment groups using Tukey's contrasts for multiple comparisons of means with an alpha level of 0.05.

RESULTS

Twenty-eight of the 149 control tortoises, 29 of 140 resident tortoises, and 89 of 357 translocated tortoises were found dead during the first year of the translocation project. While it is difficult to discern between predation and scavenging (e.g. Peterson 1994, Nussear 2004, Field et al. 2007), we think that the vast majority of these tortoises were killed by predators, because of the very detailed research histories of each tortoise in combination with the frequency of monitoring, the fact that the tortoises were overtly healthy when last observed, and the evidence of predation in relation to the carcasses (i.e. fresh predator tracks and scat, and chew marks). Although tracks and feces of coyotes were present in association with a large number of the tortoise carcasses, coyotes were observed infrequently.

Model selection by AIC yielded a model where the likelihood of mortality was most parsimoniously explained by the size of the human population, the surface roughness of the area, and the size and sex of the animal (Table 1), but with potential influences of elevation, distance to population center, and road densities all as potential contributors (models 2, 3, and 4; Table 1). Treatment group (i.e. translocated, resident, control) did not provide a significant contribution to any of the better performing models (e.g. there was an increase in AICc over the best models by 2.5 to 3 points on inclusion). The best treatment group model only had 5% support in our model set, and the data provided <16% combined relative support among all models that included treatment group as a factor (Σw_{Trans} = 0.16; Table 1). Furthermore, the addition of translocation group to the best model yielded an increase in AICc of ~3.4 with very little difference in residual model deviance (Table 1), indicating that it was not an improvement of the model (Anderson 2008). The distance to the nearest urban area provided only marginal improvement to the model either in addition to, or over using the estimated human population density, which likely reflects that the population density of the urban area has a stronger influence than the distance from urbanization in and of itself.

For the purpose of providing results of an analysis using traditional probabilistic methods, contrasts among treatment groups were analyzed using Tukey's contrasts for multiple comparisons of means. These analyses further supported that translocated tortoises had levels of mortality that were not detectably differ-

Table 1. Models considered and ranked according to Akaike's Information Criterion corrected for small sample size (AICc) and change in AICc (ΔAICc); w_i is the Akaike weight. Where models performed similarly, the model with the fewest factors was preferred. Pop: human population index, Ruf: surface roughness, Sex: sex of animal, MCL: midline carapace length, Elev: elevation, Urb: distance from nearest urban area, Road: number of road segments km^{-2}, Trans: treatment group (translocated, resident, or control)

Model	AICc	ΔAICc	w_i	Deviance
{Pop,Ruf,Sex,MCL}	603.03	0.000	0.177	592.9
{Pop,Ruf,Sex,MCL,Elev}	603.04	0.002	0.177	590.9
{Pop,Ruf,Sex,MCL,Elev,Urb}	603.46	0.421	0.144	589.2
{Pop,Ruf,Sex,MCL,Elev,Urb,Road}	603.53	0.491	0.139	587.2
{Pop,Ruf,Sex,MCL,Sex × MCL}	603.94	0.908	0.113	591.77
{Pop,Ruf,MCL}	604.5	1.465	0.085	596.41
{Pop,Ruf,Sex,MCL,Elev,Urb,Road,Trans}	605.56	2.528	0.050	585.15
{Pop,Ruf,Sex,MCL,Elev,Trans}	605.88	2.844	0.043	589.59
{Pop,Ruf,Sex,MCL,Elev,Urb,Trans}	606.21	3.179	0.036	587.87
{Pop,Ruf,Sex,MCL,Trans}	606.43	3.397	0.032	592.21
{Pop,Ruf,Sex,Elev}	613.46	10.426	0.001	603.46
{Pop,Ruf,Sex,Elev,Urb}	613.71	10.673	0.001	601.53
{Pop,Ruf,Sex}	614.69	11.651	0.001	606.59
{Pop,Ruf,Sex,Elev,Urb,Road,Trans}	615.73	12.698	0.000	597.39
{Pop,Ruf,Sex,Elev,Urb,Trans}	616.36	13.324	0.000	600.08
{Pop,Ruf,Sex,Elev,Trans}	616.44	13.407	0.000	602.22
{Pop,Ruf,Sex,Trans}	618.1	15.065	0.000	605.92
{Pop,Ruf}	630.33	27.291	0.000	624.26
{Pop}	657.39	54.358	0.000	653.35
{Intercept only}	692.47	89.436	0.000	690.45

ent from those of residents ($z = -0.401$, $p = 0.91$) and controls ($z = 0.569$, $p = 0.84$). Furthermore, resident and control tortoises also experienced similar levels of mortality ($z = 0.805$, $p = 0.70$). This indicates that the translocation was not a contributing factor to mortality, as mortality was indistinguishable between groups.

The directions of the coefficients (positive or negative) included in the final model (lowest AICc and most parsimonious) indicate the positive and negative relationships among tortoise mortality and the habitat covariates that we analyzed (Table 2). Tortoises were more likely to experience mortality in areas with elevated human population densities (Fig. 3). We hypothesized that surface roughness would correlate with increased predator densities and potentially higher incidence of predation, but the direction of the correlation was negative, indicating that tortoises were more likely to suffer mortality in flat open areas than rough higher-elevation sites. Finally, smaller tortoises and females tended to have higher mortality than larger tortoises and males (Table 2), although there was no size-by-sex interaction that contributed significantly to the model (Table 1).

Evaluation of adult desert tortoise mortality data at 9 sites across the Mojave Desert indicated that mortality among 7 of 9 populations of apparently healthy and vigorous tortoises was exceptionally high and widespread (Table 3, Fig. 3). Mortality rates at sites spanning the Mojave Desert ranged from 0.0 to 43.5%, where 2 of the sites had 0 mortality observed and 7 sites had some mortality in at least 1 of 3 years reported here. The mortality that occurred in 2008 was notably higher than in either of the previous years.

DISCUSSION

Some attributes of the desert tortoises appeared to contribute to elevated mortality rates. First, females were more likely than males to be killed by coyotes. This was counter to what might be expected, as male tortoises are known to have larger home ranges (Berry 1986, O'Connor et al. 1994, Harless et al. 2009) and generally move greater distances, especially after translocation (Nussear 2004, Field et al. 2007). Elevated female mortality has been reported elsewhere (SAIC 1993, Field et al. 2007), and Riedle et al. (2010) found higher mortality among female than among male desert tortoises at a Sonoran Desert site. Most mortality at the Sonoran site was a result of mountain lion predation and could have affected females more in early spring, because they tend to be more active earlier in the season than males in the Sonoran Desert. We are not aware of any other behaviors that are gender specific that would afford greater survival in a confrontation with a coyote. However, we found that smaller tortoises also suffered higher mortality rates. Females generally do not grow as large as adult males, and as shell size increases, the angle of curvature on the shell increases, perhaps resulting in a greater difficulty in the ability of potential predators to gain purchase on the shell of larger tortoises such as adult males. It is possible that because adult female tortoises are generally smaller than adult males (Woodbury & Hardy 1948), body size of the tortoise in relation to the gape of coyotes can explain why males fall prey to coyotes less frequently than females. This higher prevalence of predation on females could lead to biased sex ratios if the pattern were to persist, and it is notable that this area has been reported to have higher male:female sex ratios in recent surveys, with values ranging from 2.56:1 to 1.05:1 (USFWS 2006, Nussear et al. 2008).

Attributes of the habitat were also correlated with mortality rates. Our analyses indicated that desert tortoise mortality was negatively correlated with high surface roughness: most of the mortality occurred on flatter areas on the landscape. In the vicinity of Ft. Irwin, areas with high surface roughness are related to mountainous slopes with shallow soils, and smoother areas generally have deeper, more friable soils found on the lower bajada. In retrospect, we hypothesize that desert tortoises inhabiting cover sites in deeper soils of the lower bajada were more susceptible to excavation by coyotes than tortoises occupying cover sites in rocky areas of high surface roughness. Some excavations were recorded in association with mortalities, but many animals were taken on the surface as well (e.g. after precipitation or during other activities).

Table 2. Analysis of variance table showing model coefficients and significance tests for the best logistic general linear model describing mortality in desert tortoises in the Superior-Cronese Desert Wildlife Management Area from 25 March 2008 to 1 January 2009

Coefficients	Estimate	SE	z	p
Intercept	45.02	8.40	5.36	<0.001
Human population (no. of people in 15 km radius)	0.05	0.01	6.95	<0.001
Surface roughness (surface area/planar area)	−42.63	8.23	−5.18	<0.001
Carapace length (mm)	−0.02	0.01	−3.69	<0.001
Sex (males relative to females)	−0.43	0.23	−1.87	0.06

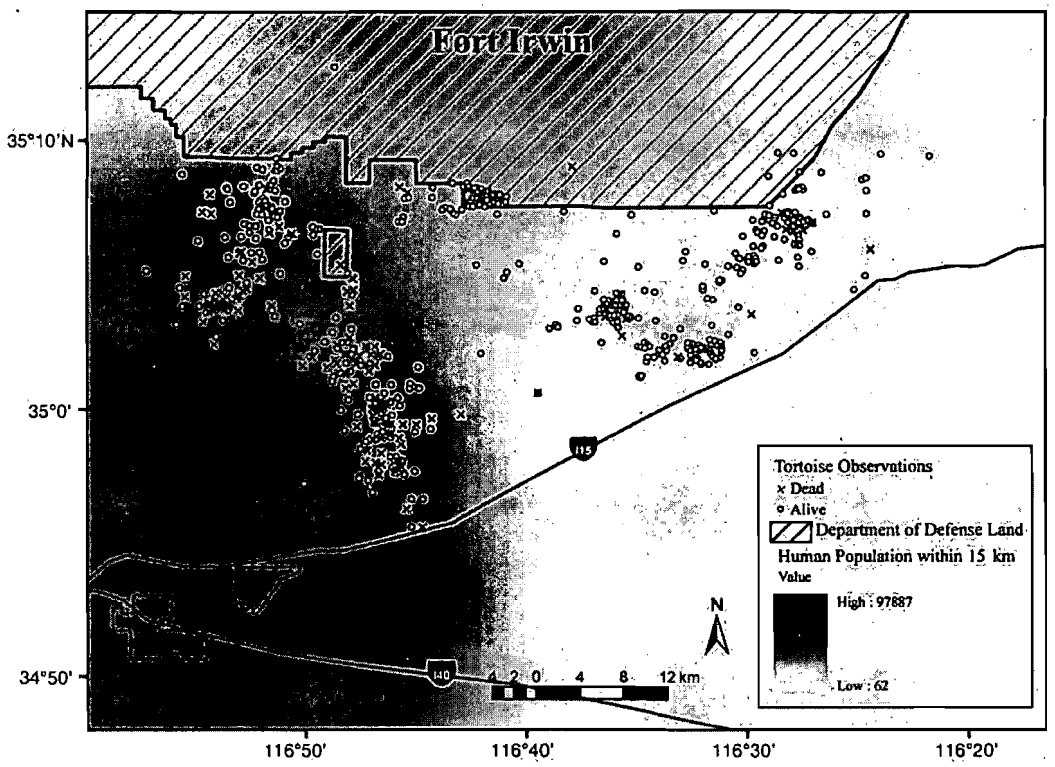

Fig. 3. *Gopherus agassizii*. Spatial pattern of mortalities (×, N = 147) and tortoises that survived (o, N = 500) with respect to the estimated human population (shading) within a 15 km radius of each 1 km^2 cell

We found that the pattern of coyote kills in the Ft. Irwin study was strongly associated with the size of nearby human populations. This variable can be regarded as a reflection of the local sphere of influence exercised by the nearby human population on desert tortoise habitat. These results are consistent with previous analyses in the region where tortoise mortalities were significantly correlated with the surface disturbances, trash, and proximity to offices and paved roads that are typical characteristics of human-populated areas (Berry et al. 2006). Urbanized areas and the resources provided by humans can elevate predator populations (Baker & Timm 1998), because garbage and other anthropogenic subsidies are incorporated into their diets (McClure et al. 1995, Fedriani et al. 2001). With locally elevated predator population sizes

Table 3. *Gopherus agassizii*. Mortality rates for sample populations of desert tortoises from locations throughout the Mojave Desert north and west of the Colorado River in 2006 to 2008. Total refers to total sample size site^{-1} yr^{-1}, Dead refers to number of mortalities site^{-1} yr^{-1}, and % mortality is the percentage of the sample population that died at each site in a given year. na: not available

Site	2006			2007			2008		
	Total	Dead	% mortality	Total	Dead	% mortality	Total	Dead	% mortality
Piute Valley, NV	20	1	5.0	19	4	21.1	22	4	18.2
Coyote Springs Valley, NV	16	0	0.0	26	0	0.0	26	5	19.2
Chemehuevi, CA	9	0	0.0	10	2	20.0	13	4	30.8
Chuckwalla, CA	11	1	9.1	12	2	16.7	14	4	28.6
Ivanpah, CA	9	0	0.0	9	0	0.0	9	0	0.0
Ord Rodman, CA	10	0	0.0	17	0	0.0	12	0	0.0
Superior-Cronese, CA	na	na	na	16	1	6.3	12	1	8.3
Soda Mountain, CA	29	0	0.0	29	5	17.2	23	10	43.5
River Mountain, NV	na	na	na	na	na	na	32	4	12.5
Average % mortality			2.0			10.2			17.9

and pulsed natural prey resources, alternative prey is likely to be affected by subsidized predators as they switch from preferred prey items (Peterson 1994, Ostfeld & Keesing 2000, Hernandez et al. 2002, Grubbs and Krausman 2009). In addition, subsidized predators may persist at artificially elevated densities beyond what a natural prey base can support, and can deplete wildlife populations in these areas (Soulé et al. 1988, Ostfeld & Keesing 2000, Fedriani et al. 2001, Kristan & Boarman 2003).

The positive relationship we found between coyote predation and human population levels illustrates that human populations can indirectly but significantly affect wildlife populations and habitat quality (Goodrich & Buskirk 1995, Ner & Burke 2008). Many aspects of human population increases cause direct losses to desert tortoise populations (reviewed by Tracy et al. 2004). For example, housing developments, utility corridors, and transportation corridors all cause direct loss of desert tortoise habitat by nature of the surface disturbances required for construction. In contrast, we illustrate how proximity to human population centers may relate to an indirect loss of desert tortoises due to subsidized predator populations, primarily coyotes.

Observations of high predation rates on adult tortoises were also widespread across the Mojave Desert in 2008. In spite of widely spread observations of mortality (7 of 9 sites), 2 sites had no observed predation, indicating the variation that occurs in the desert. Both of these sites are notably distant from sources of predator subsidization. Although no temporal prey base data are available for analysis from our study sites, we hypothesize that high predation rates by coyotes on desert tortoises were strongly influenced by low population levels of normal prey bases for coyotes (Rogers 1965, MacCracken & Hansen 1987, Ortega 1987). Small mammals, such as lagomorphs (Clark 1972, Saethre 1995) and rodents, may be particularly vulnerable to drought and are known to decrease to densities as low as 1 ha^{-1} when drought conditions prevail for 1 yr or more (Chew & Butterworth 1964, Whitford 1976, Brown & Harney 1993). In our study areas, drought occurred in the year prior to the majority of predation events. Similar observations of predation have been made by those conducting desert tortoise research, beginning with the seminal work of Woodbury & Hardy (1948), who observed that predation on desert tortoises increased in 1945 and 1946 when the numbers of rabbits and rodents were low. Similar observations continued across decades of field research, and each time a low prey base was invoked – although in none of these cases was the prey base actually quantified (Turner et al. 1984, Peterson 1994, Nussear 2004, Field et al. 2007). Bridging this gap in ecological information would be an excellent way to test this hypothesis; however, this type of work is extremely difficult to implement and fund, as annual rainfall conditions and productivity are highly variable in the Mojave Desert (Beatley 1969, 1976).

The mortality levels we report for 2008 across 9 study sites throughout the Mojave indicate that high predation rates may be more common than generally considered, which could impact the conservation status of the tortoise range-wide. For example, population viability analyses typically indicate that the most important demographic group to maintain sustainable populations is adult females (Doak et al. 1994, USFWS 1994) and that mortality rates as high as some of those in 2008 would eventually lead to local extirpations. The information presented in the present study demonstrates that mortality events can occur in pulses that track the large-scale climatic fluctuations in the Mojave Desert. Mortality as a direct impact of drought has been reported for desert tortoises (Germano & Joyner 1989, Peterson 1994, Longshore et al. 2003). However, while elevated mortality may be coupled to natural processes, we do not consider the levels of mortality we quantified to be possible naturally because they clearly would result in unsustainable population losses over the course of decades (Doak et al. 1994, USFWS 1994). While predator control is one option that is considered when local predation levels decimate species of concern, predator control programs designed to benefit at-risk species have had mixed results. Intensive predator removal sometimes results in short-term benefits, but even successful removal may have undesirable consequences for at-risk species, leading, for example, to changes in community structure, compensatory predator migration or reproduction, and/or an increase in disease (Cypher & Scrivner 1992, Goodrich & Buskirk 1995, Crooks & Soulé 1999, Berger 2006). In light of the uncertainty involved with predator control techniques and the disparate responses of public opinion, resource managers will need to consider the efficacy, costs/benefits, and socio-economic (or socio-political) implications of potential management strategies before selecting an appropriate course of action. Alternatively, modifying human behavior around habitations and recreation areas to limit the amount of refuse and minimize the availability of access to water in desert areas would likely be useful in reducing subsidized predators.

Determining direct causality of population changes to desert tortoise populations has proven to be challenging (Tracy et al. 2004, USFWS 2008). It is difficult to study wild animals such as the desert tortoise without introducing observer bias such as the potential influence of attaching radio transmitters and repeatedly visiting the animals in the field. In a study to compare the influence of humans and dogs on desert tor-

toise survival at Ft. Irwin, no influence of either was detected on their survival (Heaton et al. 2008b). Furthermore, since the 1980s, many 100s of radio-telemetered tortoises have been followed at multiple sites for multiple years with multiple research teams, and incidence of high mortality was quite rare. Other hypothesized mechanisms for heightened predation levels include increased movements of tortoises that were translocated (Nussear 2004, Field et al. 2007), potential unavailability or unfamiliarity with locations of cover sites, food and water, and the attraction of predators to areas with increased tortoise densities and increased human activity. However, translocated, control, and resident animals did not differ statistically in mortality rates from one another. This eliminated not only the translocation itself as a factor in mortality, but also the possible influence of increased densities, as the control tortoises were maintained at natural densities while both resident and translocated tortoises being co-located necessarily increased density. Considering all these factors as well as analyses of animal size and sex, proximity to urban areas, surrounding human population density, road density, and regional predation patterns, we conclude that what we observed was a severe range-wide predation pulse that may reflect the status of the Mojave Desert in its entirety rather than being the result of a single management activity.

The coincidence of widespread and high predation rates with the translocation was unfortunate. However, there was no evidence that the translocation influenced the high predation rate at Ft. Irwin NTC. Instead, data available to us indicate that the phenomenon was widespread across the desert. We view this as a result of both the increasing growth of human populations in the arid southwest (Grimm et al. 2008) and the general and widespread habitat degradation associated with human population growth (Leu et al. 2008), which may partially explain long-term negative trends in desert tortoise populations. It is likely that high predation rates and a myriad of other threats to tortoise populations (Tracy et al. 2004) will continue to increase across the Mojave Desert as metropolitan areas increase in size (Grimm et al. 2008), and the footprint of humans spreads into currently less impacted areas of the desert southwest (Leu et al. 2008). This highlights that protecting sensitive species is not simply a matter of protecting total acreage at multiples of individual home range, but is a matter of effective protected area design with minimal-impact core wilderness areas of sufficient size surrounded by adequate-sized buffer zones. It reiterates the value of careful consideration of infrastructure and its impact on sensitive areas and provides opportunities for novel and creative approaches to mitigation and compensation for development near protected areas.

Acknowledgements. We are indebted to the staff of numerous organizations and individuals that participated in gathering much of these data throughout the Mojave Desert during the 2005 through 2008 field seasons, including: ITS – A QinetiQ North American Company, Student Conservation Association, Kiva Biological Consulting, USFWS/Desert Tortoise Recovery Office, US Geological Survey/Biological Resources Discipline, Henderson, Nevada, and Moreno Valley, California. A. Grimmer assisted with GIS and figures. C.R. Darst, B. Cypher, E. Boydston, and 3 anonymous reviewers provided comments and valuable discussion on earlier versions of this manuscript. This project was supported by the US Department of Defense, National Training Center, Ft. Irwin, California. These studies were conducted under Threatened Species permit TE-102235, TE-006556-13, and TE-006556-14 issued by the USFWS, and the California Game and Fish Department, Scientific Collection Permit no. SCP-801179. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the USFWS or US Geological Survey. Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the US government.

LITERATURE CITED

Anderson DM (2008) Model based inference in the life sciences: a primer on evidence. Springer Science + Business Media LLC, New York, NY

Baker RO, Timm RM (1998) Management of conflicts between urban coyotes and humans in Southern California. In: Baker RO, Crabb AC (eds) Proc 18th Vertebr Pest Conf. University of California, Davis, CA, p 299–312

Beatley JC (1969) Dependence of desert rodents on winter annuals and precipitation. Ecology 50:721–724

Beatley JC (1976) Rainfall and fluctuating plant populations in relation to distributions and numbers of desert rodents in southern Nevada. Oecologia 24:21–42

Berger KM (2006) Carnivore-livestock conflicts: effects of subsidized predator control and economic correlates on the sheep industry. Conserv Biol 20:751–761

Berry KH (1986) Desert tortoise (*Gopherus agassizii*) relocation: implications of social behavior and movements. Herpetologica 42:113–125

Berry KH, Bailey TY, Anderson KM (2006) Attributes of desert tortoise populations at the National Training Center, Central Mojave Desert, California, USA. J Arid Environ 67: 165–171

Boarman WI, Goodlett T, Goodlett GC (1998) Review of radio transmitter attachment techniques for chelonian research and recommendations for improvement. Herpetol Rev 29: 26–33

Brown JH, Harney BA (1993) Population and community ecology of heteromyid rodents in temperate habitats. In: Genoways HH, Brown JH (eds) Biology of the Heteromyidae. American Society of Mammalogists Special Publication No. 10. American Society of Mammalogists. Provo, UT, p 618–647

Burnham KP, Anderson DR (2002) Model selection and multimodel inference: a practical information-theoretic approach. Springer-Verlag, New York, NY

Chew RM, Butterworth BB (1964) Ecology of rodents in Indian Cove (Mojave Desert), Joshua Tree National Monument, California. J Mammal 45:203–225

Clark FW (1972) Influence of jackrabbit density on coyote population change. J Wildl Manag 36:343–356

Crooks KR, Soulé ME (1999) Mesopredator release and avi-

faunal extinctions in a fragmented system. Nature 400: 563–566

Cypher BL, Scrivner JH (1992) Coyote control to protect endangered San Joaquin kit foxes at the Naval Petroleum Reserves, California. Proc 15th Vertebr Pest Conf, University of California, Davis, CA, p 42–47

Doak D, Kareiva P, Klepetka B (1994) Modeling population viability for the desert tortoise in the western Mojave Desert. Ecol Appl 4:446–460

Esque TC, Nussear KE, Medica PA (2005) Desert tortoise translocation plan for Fort Irwin's land expansion program at the U.S. Army National Training Center (NTC) at Fort Irwin. Prepared for U.S. Army National Training Center, Directorate of Public Works. Available at www.fortirwinlandexpansion.com/Documents.htm

Fedriani JM, Fuller TK, Sauvajot RM (2001) Does availability of anthropogenic food enhance densities of omnivorous mammals? An example with coyotes in southern California. Ecography 24:325–331

Field KJ, Tracy CR, Medica PA, Marlow RW, Corn PS (2007) Return to the wild: translocation as a tool in conservation of the desert tortoise (*Gopherus agassizii*). Biol Conserv 136:232–245

Germano DJ, Joyner MA (1989) Changes in a desert tortoise (*Gopherus agassizii*) population after a period of high mortality. In: Szaro RC, Severson KE, Patton DR (eds) Management of amphibians, reptiles and small mammals in North America. Gen Tech Rep RM-66, USDA Forest Service, Ft. Collins, CO, p 190–198

Germano DJ, Bury RB, Esque TC, Fritts TH, Medica PA (1994) Range and habitats of the desert tortoise. In: Bury RB, Germano DJ (eds) Biology of North American tortoises. Fish Wildl Res 13, USDI National Biological Survey, Washington, DC, p 73–84

Gompper ME, Vanak AT (2008) Subsidized predators, landscapes of fear and disarticulated carnivore communities. Anim Conserv 11:13–14

Goodrich JM, Buskirk SW (1995) Control of abundant native vertebrates for conservation of endangered species. Conserv Biol 9:1357–1364

Grimm NB, Foster D, Groffman P, Grove JM, Hopkinson CS, Nadelhoffer KJ, Pataki DE, Peters DPC (2008) The changing landscape: ecosystem responses to urbanization and pollution across climatic and societal gradients. Front Ecol Environ 6:264–272

Grover M, DeFalco LA (1995) Desert tortoise (*Gopherus agassizii*): status-of-knowledge outline with references. Gen Tech Rep INT-GTR-316. USDA Forest Service, Intermountain Research Station, Ogden, UT

Grubbs SE, Krausman PR (2009) Observations of coyote–cat interactions. J Wildl Manag 73:683–685

Harless ML, Walde AD, Delaney DK, Pater LL, Hayes WK (2009) Home range, spatial overlap and burrow use of the desert tortoise in the West Mojave Desert. Copeia 2009: 378–389

Heaton JS, Nussear KE, Esque TC, Inman RD and others (2008a) Spatially explicit decision support for selecting translocation areas for desert tortoises. Biodivers Conserv 17:575–590

Heaton JS, Cablk ME, Nussear KE, Esque TC, Medica PA, Sagebiel JC, Francis S (2008b) Comparison of effects of humans versus wildlife-detector dogs. Southwest Nat 53: 472–479

Hernandez L, Parmenter RR, Dewitt JW, Lightfoot DC, Laundre JW (2002) Coyote diets in the Chihuahuan Desert, more evidence for optimal foraging. J Arid Environ 51: 613–624

Inman RD, Nussear KE, Tracy CR (2009) Detecting trends in population growth: elusive behavior inflates variance in estimates of population density. Endang Species Res 10: 295–304

Kristan WB III, Boarman WI (2003) Spatial distribution of risk of desert tortoise (*Gopherus agassizii*) predation by common ravens (*Corvus corax*). Ecology 84:2432–2443

Leu M, Hanser SE, Knick ST (2008) The human footprint in the west: a large-scale analysis of anthropogenic impacts. Ecol Appl 18:1119–1139

Longshore KM, Jaeger JR, Sappington JM (2003) Desert tortoise (*Gopherus agassizii*) survival at two eastern Mojave Desert sites: death by short-term drought? J Herpetol 37: 169–177

Luckenbach R (1982) Ecology and management of the desert tortoise (*Gopherus agassizii*) in California. In: Bury RB (ed) North American tortoises: conservation and ecology. Wildl Res Rep12, USDI Fish and Wildlife Service, Washington, DC, p 1–38

MacCracken JG, Hansen RM (1987) Coyote feeding strategies in southeastern Idaho: optimal foraging by an opportunistic predator? J Wildl Manag 51:278–285

McClure MF, Smith NS, Shaw WW (1995) Diets of coyotes near the boundary of Saguaro National Monument and Tucson, Arizona. Southwest Nat 40:101–125

Medica PA, Greger PD (2009) *Gopherus agassizii* (desert tortoise), predation by mountain lion. Herpetol Rev 40:75–77

Ner S, Burke RL (2008) Direct and indirect effects of urbanization on diamondback terrapins of New York City: distribution and predation of terrapin nests in a human-modified estuary. In: Mitchell JC, Jung RE, Bartholomew B (eds) Urban herpetology. Herpetological Conservation Vol 3. Society for the Study of Amphibians and Reptiles, Salt Lake City, UT, p 107–117

Nussear KE (2004) Mechanistic investigation of the distributional limits of the desert tortoise *Gopherus agassizii*. PhD dissertation, University of Nevada, Reno, NV

Nussear KE, Esque TC, Heaton JS, Cablk ME, Drake KK, Valentin C, Yee JL, Medica PA (2008) Are wildlife detector dogs or people better at finding desert tortoises (*Gopherus agassizii*)? Herpetol Conserv Biol 3:103–115

O'Connor MP, Zimmerman LC, Ruby DE, Bulova SJ, Spotila JR (1994) Home range size and movements by desert tortoises, *Gopherus agassizii*, in the eastern Mojave Desert. Herpetol Monogr 8:60–71

Ortega JC (1987) Coyote food habits in southeastern Arizona. Southwest Nat 32:152–155

Ostfeld RS, Keesing F (2000) Pulsed resources and community dynamics of consumers in terrestrial ecosystems. Trends Ecol Evol 15:232–237

Peterson CC (1994) Different rates and causes of high mortality in two populations of the threatened desert tortoise *Gopherus agassizii*. Biol Conserv 70:101–108

R Development Core Team (2009) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. http://www.R-project.org

Reyes Osorio S, Bury RB (1982) Ecology and status of the desert tortoise (*Gopherus agassizii*) on Tiburon Island, Sonora. In: Bury RB (ed) North American tortoises: conservation and ecology. Wildl Res Rep 12. USDI Fish and Wildlife Service, Washington, DC, p 39–50

Riedle JD, Averill-Murray RC, Grandmaison DD (2010) Seasonal variation in survivorship and mortality of desert tortoises in the Sonoran Desert, Arizona. J Herpetol 44: 164–167

Rogers JG (1965) Analysis of the coyote population of Doña Ana County, New Mexico. MS thesis, New Mexico State

University, Las Cruces City, NM
Saethre MB (1995) Small mammal populations on the Nevada Test Site, 1994. In: Hunter RB (comp) Status of the flora and fauna on the Nevada Test Site, 1994. DOE.NV/11432-195. Department of Energy, Las Vegas, NV, p 75–148
SAIC (Science Applications International Corporation) (1993) American Honda desert tortoise relocation project: final report. US Fish and Wildlife Service, Portland Regional Office, Portland, OR
Soulé ME, Bolger DT, Alberts AC, Wright J, Sorice M, Hill S (1988) Reconstructed dynamics of rapid extinctions of chaparral-requiring birds in urban habitat islands. Conserv Biol 2:75–92
Tracy CR, Averill-Murray R, Boarman W, Delehanty D and others (2004) Desert tortoise recovery plan assessment. Report to US Fish and Wildlife Service. Available at www.fws.gov/nevada/desert_tortoise/documents/dtrpac/dtrpac_report.pdf
Turner RM (1994) Mojave desertscrub. In: Brown DE (ed) Biotic communities, southwestern United States and northwestern Mexico. University of Utah Press, Salt Lake City, UT, p 157–168
Turner FB, Medica PA, Lyons CL (1984) Reproduction and survival of the desert tortoise (*Scaptochelys agassizii*) in Ivanpah Valley, California. Copeia 1984:811–820
US Census Bureau (2000) US census 2000. Available at www.census.gov/main/www/cen2000.html
USFWS (US Fish and Wildlife Service) (1994) Desert tortoise (Mojave population) Recovery Plan. USFWS, Portland, OR
USFWS (2006) Range-wide monitoring of the Mojave population of the desert tortoise: 2001–2005 summary report. Desert Tortoise Recovery Office, USFWS, Reno, NV
USFWS (2008) Draft revised recovery plan for the Mojave population of the desert tortoise (*Gopherus agassizii*). USFWS, California and Nevada Region, Sacramento, CA
Whitford WG (1976) Temporal fluctuations in density and diversity of desert rodent populations. J Mammal 57: 351–369
Woodbury AM, Hardy R (1948) Studies of the desert tortoise, *Gopherus agassizii*. Ecol Monogr 18:145–200

Editorial responsibility: Luca Luiselli, Rome, Italy

Submitted: January 6, 2010; Accepted: June 14, 2010
Proofs received from author(s): July 24, 2010

J. Field Ornithol., 57(2):135–141

AVIAN MORTALITY AT A SOLAR ENERGY POWER PLANT

By Michael D. McCrary, Robert L. McKernan, Ralph W. Schreiber, William D. Wagner, and Terry C. Sciarrotta

In 1979, the United States Department of Energy, in conjunction with the Southern California Edison Company (SCE) and the Los Angeles Department of Water and Power, initiated the construction of Solar One, the world's largest solar energy power plant (Fig. 1). Until the construction of Solar One, the use of the sun's energy to produce electrical power had not been attempted on this scale, and the environmental hazards of operation of a solar power plant were unknown. In this paper we report on bird mortality at Solar One.

STUDY AREA AND METHODS

Solar One is a 10 megawatt, central receiver solar power plant consisting of a 32-ha field of 1818, 6.9 × 6.9 m mirrors (heliostats) which concentrate sunlight on a centrally located, tower-mounted boiler, 86 m in height (Fig. 1). The reflective surface area of each heliostat is approximately 40 m^2, and the total for all heliostats is approximately 72,500 m^2. When not directed at the tower during morning startup, testing, and maintenance, some or all of the heliostats are focused on standby points, four small areas (approximate diameter = 5 m) of sky around the tower at a height of 80 m. Temperatures within the standby points vary with the number of heliostats focused on them and the reflectivity of an object placed within them, but the temperature can be high enough to burn feathers and small insects.

Solar One is located in the Mojave Desert, 4 km east of Daggett, San Bernardino County, California (34°52′N, 116°51′W). The dominant desert plant community in this area is creosote bush (*Larrea divaricata*) scrub, although abandoned and active agricultural fields (alfalfa) and extensive (53 ha) evaporation ponds (Fig. 1) are adjacent to Solar One.

We visited Solar One approximately once per week (2–3 days per visit) on 6 occasions from 3 May through 8 June 1982 and on 34 occasions from 16 September 1982 through May 1983. During each visit 1–2 observers searched the facility for any evidence of bird mortality. Although searches were not conducted in a fixed pattern, the entire facility was covered during each visit. Bird carcasses were readily found because of the sparse vegetation and level ground of Solar One. Experiments involving the placement of 19 bird carcasses of various species within and just outside (<200 m) the fenced facility were conducted in May and September 1982 to measure the rate of bird carcass removal by scavengers. These carcasses were checked periodically until removed by scavengers or decomposed.

FIGURE 1. Aerial view of Solar One: (A) heliostat field, (B) central receiver tower, (C) evaporation ponds. Tower height = 86 m, diameter of field = 765 m.

To determine the impact of bird mortality on local populations, 1–2 observers conducted surveys of relative avian abundance within an area of approximately 150 ha surrounding Solar One, concentrating on the facility grounds (32 ha), evaporation ponds, and agricultural fields. These surveys were conducted on at least 2 d per visit for 3–4 h/d.

RESULTS

Solar One related animal mortality.—During approximately 40 wks of study, we documented 70 bird fatalities involving 26 species at Solar One (Table 1). The mean rate of mortality between visits was 1.7 birds ± 1.8 SD (n = 40, range 0–7). Results of the scavenger bias experiments indicate that from 10–30% of carcasses were removed between searches, thus, the actual rate of mortality may have been from 1.9–2.2 birds. Two causes of avian mortality were identified at Solar One, colliding with structures and burning from standby points.

The most frequent form of avian mortality was from collisions with Solar One structures. We documented 57 (81%) bird deaths (20 species) from collisions (Table 1). In most cases the cause of death was determined by the presence of broken bones (usually mandibles or wings) found through external examination. From the location of birds in relation to structures, most (>75%) died from colliding with the mirrored heliostats, although a dead Blue-winged Teal (*Anas discors*) with a broken wing was found on a platform of the receiver tower. On one occasion

TABLE 1. Avian mortality from burning and collisions at Solar One, 1982–1983.

Burn fatalities		Collision fatalities	
Species	Number of individuals	Species	Number of individuals
Vaux's Swift (*Chaetura vauxi*)	1	Eared Grebe (*Podiceps nigricollis*)	11
White-throated Swift (*Aeronautes saxatalis*)	2	Blue-winged Teal (*Anas discors*)	1
Hummingbird sp.	3	American Kestrel (*Falco sparverius*)	1
Cliff Swallow (*Hirundo pyrrhonota*)	2	American Coot (*Fulica americana*)	2
Barn Swallow (*Hirundo rustica*)	1	Black-necked Stilt (*Himantopus mexicanus*)	2
Barn Swallow (*Hirundo rustica*)	1	Sandpiper sp.	1
Yellow-rumped Warbler (*Dendroica coronata*)	1	Red-necked Phalarope (*Phalaropus lobatus*)	1
Wilson's Warbler (*Wilsonia pusilla*)	1	Bonaparte's Gull (*Larus philadelphia*)	1
Sparrow sp.	1	Mourning Dove (*Zenaida macroura*)	6
		Hummingbird sp.	1
		Horned Lark (*Eremophila alpestris*)	3
		European Starling (*Sturnus vulgaris*)	4
		Yellow-rumped Warbler (*Dendroica coronata*)	1
		MacGillivray's Warbler (*Oporornis tolmiei*)	1
		Savannah Sparrow (*Passerculus sandwichensis*)	3
		White-crowned Sparrow (*Zonotrichia leucophrys*)	2
		Dark-eyed Junco (*Junco hyemalis*)	1
		Red-winged Blackbird (*Agelaius phoeniceus*)	3
		Western Meadowlark (*Sturnella neglecta*)	1
		Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*)	2
		Brewer's Blackbird (*Euphagas cyanocephalus*)	5
		House Finch (*Carpodacus mexicanus*)	4
Total	13	Total	57

in May 1982 a Solar One employee observed 4 Mourning Doves (*Zenaida macroura*) die in a collision with a single heliostat.

Thirteen (19%) birds (7 species) died from burning in the standby points (Table 1). Although we never observed a bird fly through one of

the standby points, the heavily singed flight and contour feathers indicated that the birds burned to death (Fig. 2). Six (46%) of these fatalities involved aerial foragers (swifts and swallows) which are apparently more susceptible to this form of mortality because of their feeding behavior. Three of these aerial foragers died during a 2-wk period in May 1982, corresponding with the presence of the highest numbers of swifts and swallows observed (>500 per d), and an extensive period of heliostat testing when the occurrence and intensity of standby points was probably greater than at other times.

Relative avian abundance.—During 102 d from May–June 1982 (18 d) and September 1982–May 1983 (84 d), we recorded 107 bird species (daily mean = 16.7 ± 6.1 SD, n = 102) in the immediate area (150 ha) of Solar One. The mean daily count for individuals was 314 ± 203 SD (range 148–1040). Most avian species recorded at Solar One were migrants and only 15 species are year-round residents, with Horned Larks (*Eremophila alpestris*), European Starlings (*Sturnus vulgaris*), and House Finches (*Carpodacus mexicanus*) the most common breeding birds.

Of the habitats surveyed in this study, the evaporation ponds were the most heavily used by birds. Seventy percent of all species were recorded at least once at the ponds, and 45% were recorded only at the ponds; the majority of daily counts recorded mostly waterbirds.

DISCUSSION

Creosote bush scrub, which characterizes much of the undisturbed portions of the Mojave Desert near Solar One, is usually only sparsely inhabited by birds. The avian community of similar habitat in Arizona is usually less than 20 species (Tomoff, Ecology 55:396–403, 1974). However, we recorded 107 species in the vicinity of Solar One, 15 of which breed in the area. The special attraction of Solar One to birds is most likely related to the presence of a large, man-made water impoundment and irrigated agricultural fields, both of which produce an abundance of insects. Naturally occurring open water sources in the Mojave Desert are rare and usually ephemeral, while the man-made ponds near Solar One are permanent.

The most frequent form of avian mortality at Solar One during this study was from collisions with structures, primarily heliostats. Avian collisions are an inevitable by-product of almost all man-made structures (see Avery et al., FWS/OBS-80/54, 1980). Reflective surfaces are especially prone to collisions (Klem, Ph.D. thesis, Southern Illinois Univ., Carbondale, 1979), and it is not surprising that collisions with mirrored heliostats occur on a somewhat regular basis considering the reflective surface area of Solar One.

A form of avian mortality unique to solar central receiver power plants is burning in standby points. Death after being burned was infrequent in occurrence at Solar One, being in part a function of the frequent absence and variable intensity of standby points and the number of aerial foragers (swifts and swallows) in the airspace over Solar One.

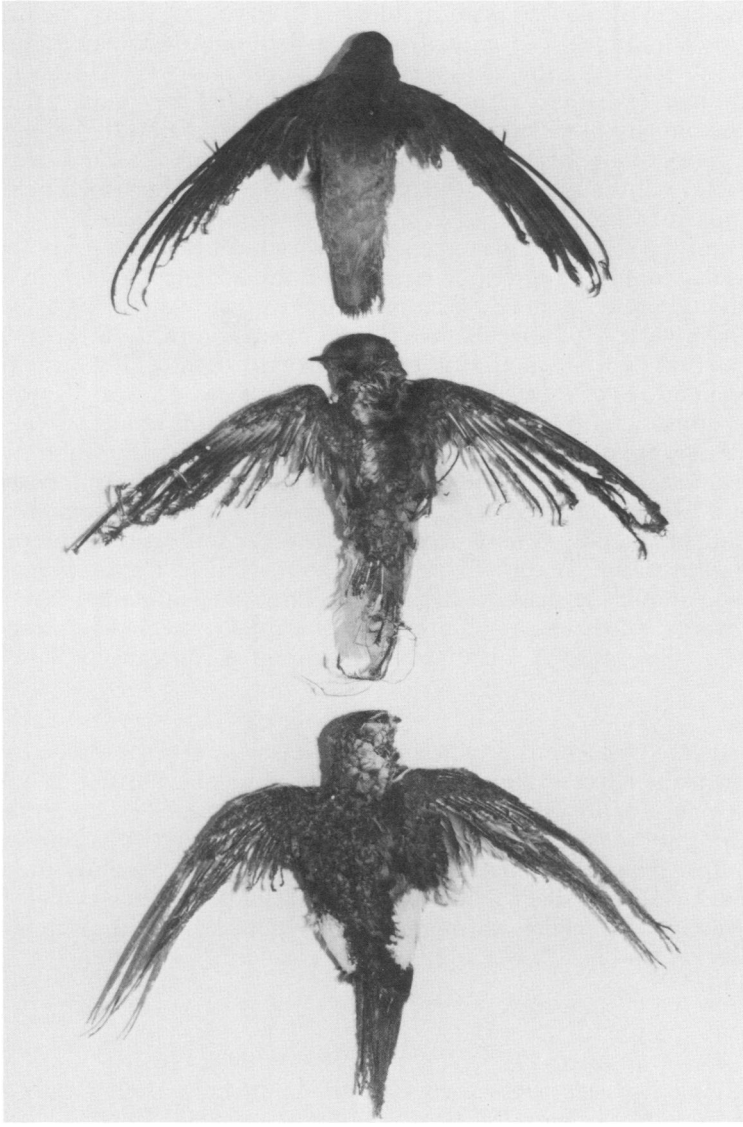

FIGURE 2. Three birds burned in standby points at Solar One. Top to bottom: Vaux's Swift (*Chaetura vauxi*), Barn Swallow (*Hirundo rustica*), and White-throated Swift (*Aeronautes saxatalis*). Note the heavily singed rectrices and remiges especially in the Barn Swallow.

Considering all known avian fatalities (70 birds) at Solar One during this study the impact of the facility on birds after construction appears minimal. Comparing the estimated rate of mortality (1.9–2.2 birds per wk) and mean relative avian abundance (314 birds per count) recorded in the vicinity of Solar One, only 0.6–0.7% of the local population present at any given time may have been affected during this study. The effect on the total population using the region in a year is obviously much less, but is unestimatable.

The results of this study suggest that, to reduce their impact on birds, future solar central receiver power plants in the Mojave Desert and other areas should not be sited in close proximity to open water or agricultural fields. The variety of species involved in avian mortality at Solar One indicates that caution should be taken when siting a solar power plant near populations of rare, threatened, or endangered species. If possible, the occurrence and intensity of standby points should be kept to a minimum. Since Solar One is only a 10 megawatt pilot facility, future projects designed to produce hundreds of megawatts will require several thousand heliostats and much taller receiver towers. The greater magnitude of these facilities may produce non-linear increases in the rate of avian mortality when compared to Solar One and extrapolations from this study should be made with caution. The removal of large tracts of desert from biological production for solar power generation and the ecological effects caused thereby should also be of concern.

SUMMARY

We studied avian mortality at an operating solar central receiver power plant in the Mojave Desert of southern California. During 40 wks of study we documented the deaths of 70 birds (26 species). The estimated mortality rate was 1.9–2.2 birds per week. Fifty-seven (81%) birds of 20 species died from collisions with Solar One structures, mainly the mirrored surfaces of heliostats. Thirteen (19%) birds (7 species) died from burns received by flying through standby points. The impact of this mortality on the local bird population is considered minimal (0.6–0.7% per wk).

ACKNOWLEDGMENTS

We thank J. Reeves (Research and Development, Southern California Edison Co.), P. Skvarna (SCE Site Manager of Solar One), D. Elliott (U.S. Department of Energy Project Director), and all other Solar One personnel for their valuable assistance on this project. P. Flanagan and G. Sawyer provided assistance in the field, and C. Barrows, P. Bloom, E. H. Burtt, Jr., J. Gore, and D. Klem provided editorial comments on the manuscript. This project was financially supported by a contract from the Southern California Edison Company to the Los Angeles County Museum of Natural History Foundation.

Los Angeles County Museum of Natural History, Section of Ornithology, 900 Exposition Blvd., Los Angeles, California 90007 (MDM, RLM, RWS, WDW); *Southern California Edison Company, Research and Development, P.O. Box 800, Rosemead, California 91770* (TCS). Received 1 Oct. 1985; accepted 24 Jan. 1986.

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COLLISIONS BETWEEN BIRDS AND WINDOWS: MORTALITY AND PREVENTION

DANIEL KLEM, JR.
Department of Zoology
Southern Illinois University at Carbondale
Carbondale, Illinois 62901 USA
Current Address: Department of Biology, Muhlenburg College, Allentown, PA 18104

Abstract.—Bird strikes were recorded at the windows of commercial and private buildings to study the effects of collision mortality on birds, and several experiments were conducted to evaluate methods of preventing collisions between birds and glass panes. Two single houses that were systematically monitored annually killed 33 and 26 birds, respectively. Collisions at one house in the same 4-mo period (September- December) in consecutive years resulted in 26 and 15 fatalities, respectively. At least one out of every two birds were killed striking the windows of these single dwellings. The records from these homes also revealed that window strikes are equally lethal for small and large species. The annual mortality resulting from window collisions in the United States is estimated at 97.6-975.6 million birds. Experimental evidence indicates that complete or partial covering of windows will eliminate bird strikes. If parts of the window are altered, objects or patterns placed on or near the window must be no more than 5-10 cm apart and uniformly cover the entire glass surface. Eliminating bird attractants from the vicinity of windows will reduce or prevent strikes by reducing the number of birds near the glass hazard. If removal of attractants is unacceptable, place them within 0.3 m of the glass surface; birds are drawn to the attractant on arrival and are not able to build up enough momentum to sustain serious injury if they hit upon departure. My experimental results further reveal that the common practice of placing single objects such as falcon silhouettes or owl decoys on or near windows does not significantly reduce bird strikes. Window casualties represent a potentially valuable, but largely neglected source of data capable of contributing information on species geographic distributions, migration patterns, and various other studies requiring specimens.

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Too often the destructive influence of human activities on bird populations is recognized only after substantial damage has been done (Soule 1986). Plate glass is a non-selective lethal hazard for free-flying birds (Townsend 1931, Banks 1976, Weir 1976, Avery et al. 1980), and human lifestyles can hide the importance of this mortality factor for select species and birds in general (Klem 1979). Modest attention and meager quantitative evidence is available to evaluate the exact or potential impact of this human-caused mortality on avian populations (Banks 1979). From analyses of bird strike accounts, a survey of window-killed specimens, and a series of experiments, I found collisions to occur wherever birds and windows coexist (Klem 1979; Klem, in press). Here I (1) present results suggesting that glass is or could become a significant mortality factor for some birds, and (2) evaluate various techniques to prevent birds from striking windows.

METHODS

From 1974 to 1986 1 collected data on birds that were injured or killed at commercial and private buildings primarily in southern Illinois but also throughout the United States and Canada. To assess avian mortality at specific structures containing windows of different sizes and shapes, planned observations were obtained from individually monitored single homes in Carbondale, Jackson Co., Illinois (37'41'25"N, 89'15'50"W) and Purchase, Westchester Co., New York (41'02'22"N, 73'42'04"W). The Carbondale house was the principal study site and is located in a rural setting surrounded by mixed trees, shrubs, field and lawn. The Purchase house is located in a suburban setting surrounded by trees, shrubs, and lawn.

Two experimental designs were used in southern Illinois. The data collected were frequency counts of bird strikes at windows. A strike was registered when a specimen was found beneath a window or a specimen remnant in the form of a feather, body smudge, or blood smear was found on the glass. These data are likely to be incomplete but a conservative measure of glass as a mortality factor; collisions may have occurred without leaving evidence, and predators and scavengers are known to collect victims from the vicinity of windows (Klem 1981). The first design consisted of a single experiment. Five identical wooden-framed picture windows were placed immediately adjacent to each other along the edge of a mixed deciduous forest and corn field. The study site was a small farm near Cobden, Union Co., Illinois (37'33'05"N, 89'15'38"W). Each window was 1.4 m wide, 1.2 m high, and mounted 1.2 m above ground. Wire mesh trays were placed under each window to catch casualties and were checked daily at dusk.

Four of the 5 windows were altered by placing objects on or around the glass; the unaltered window served as a control. On one window, a diving falcon silhouette, 23.6 cm in length and with 45.4 cm wing spread was attached in the upper left corner as you face the window and angled downward such that it appeared to be stooping toward prey; it is an exact replica of a commercially available silhouette sold to prevent bird strikes. A Great Horned Owl *(Bubo virginianus)* replica, used to frighten birds at food processing plants, was placed such that it appeared perched in front of and at the bottom center of another window. Wind chimes constructed with 5 hollow metal cylinders that dangle on monofilament line from a star-shaped metal cap (length 35 cm, width 7.8 cm at the top) were hung in front of the top center of the window, and when activated by wind, the chimes combine sound and motion to frighten birds from windows. A light set of 7-watt clear bulbs placed 30.5 cm apart was placed around an entire window, and set to blink 32 times per minute. They were visible from both sides of the glass. An automatic timer turned the lights on and off at first and last light, respectively. The experiment was conducted over 52 days during which the preventative methods and control were randomly assigned on a daily basis.

The second design consisted of several experiments in which six Dark-eyed Juncos *(Junco hyemalls)* were tested in an outdoor flight cage. Juncos were captured in April and early May, housed in small flight cages, and tested throughout May. The flight cage was trapezoidal and 1.2 m high, 3.6 m in length, 0.3 m wide at the narrow end and 2.6 m wide at the broad end. Individuals were released from a holding box at the narrow end and forced to discriminate between left or right flight paths as they attempted to escape to wooded habitat visible outside the broad end of the cage. At the broad end, one half of the cage was left unobstructed in all experiments. The other half was obstructed by clear glass or various objects expected to prevent bird strikes. Actual glass was used only in experiments that tested techniques similar to those in the field experiment. To prevent accidental collision injuries to subjects in subsequent experiments, objects were hung on the

obstructed side with clear monofilament line in order to appear as if taped to glass.

Twenty-seven experiments were conducted. Each tested one subject and consisted of 10 to 30 trials in which I recorded whether a Junco passed through the unobstructed side of the cage or the side with a preventative object. If the subject chose the obstructed side it was scored as a window strike. On any test day, a group of five or fewer preventative methods was evaluated. Subjects were tested with a single preventative method on any one test-day, and each subject was tested with each of the methods in a group on consecutive test-days. The objects tested were: (1) clear glass; (2) small diving falcon silhouette in upper left corner of pane (18.8 cm in length, 35.6 cm wing-spread); (3) the same small diving falcon silhouette in center of window; (4) large diving falcon silhouette (same as field experiment); (5) Barred Owl *(Strix varia)* silhouette (39.6 cm in length, 17.1 cm in width at breast); (6) mounted Barred Owl specimen at bottom center of pane (same dimensions as Barred Owl silhouette),(7) circle silhouette in center of pane (17.8 cm in diameter); (8) two vertebrate eyes in center of pane (each eye 10.2 cm in diameter, separated by 1.3 cm, and patterned after lepidopteran eyespots found by Blest (1957) to be most effective in frightening birds); (9) wind chimes (same as field experiments but without motion and sound); (10) the same wind chimes with motion and sound; (11) blinking lights (same as field experiment); (12) hanging ivy plant in planter at top-center of pane (35.6 cm in length, 12.7 cm pot diameter); (13) blinking lights around the same hanging ivy plant in planter at top-center of pane; (14) white cloth drapes covering entire pane,- 2.5 cm white cloth strips placed horizontally and vertically, and uniformly covering pane with mesh openings (width by height): (15) 43 x 58 cm, (16) 30 x 38 cm, (17) 20 x 30 cm, (18) 13 x 18 cm, (19) 10 X 13 cm, and (20) 8 x 10 cm; (21) single vertical 2.5 cm white cloth strip in center of pane; (22) single horizontal white cloth strip in center of pane; vertical 2.5 cm white cloth strips uniformly covering pane and separated by: (23) 18 cm, (24) 10 cm and (25) 5 cm; horizontal 2.5 cm white cloth strips uniformly covering pane and separated by: (26) 10 cm and (27) 5 cm. Binomial tests were used to determine the significance of each experiment (Siegel 1956).

RESULTS

Annual fatalities resulting from window collisions were 33 (54.1%) of 61 strikes at the Carbondale house and 26 (55.3%) of 47 strikes at the Purchase house. Collisions at the Purchase house in the same 4-mo period (September to December) in consecutive years resulted in 26 (76.5%) fatalities from 34 strikes the first year, and 15 (51.7%) fatalities from 29 strikes the next. These data indicate that mortality rates may vary as much as 24.2% from one year to another at one locality, and at least at these houses, one out of every two birds is killed striking windows.

These same data were used to determine the vulnerability of different size birds. No significant differences in mortality rates were found for two arbitrary weight classes (0-39 g, hummingbirds-sparrows and >39 g, cardinals-bobwhite) at either the Carbondale ($P > 0.5$, $_X^2 = 0.18$) or Purchase ($P > 0.5$, $_X^2 = 0.94$) houses.

Thirty-three collisions were registered in the field experiment, and of these 18 (54.5%) were fatal. The distribution of strikes among the control and altered windows was not significantly different from a uniform distribution ($P > 0.05$, $_X^2 = 8.7$). These results indicate that the diving falcon silhouette, owl decoy, wind chimes, and blinking lights do not significantly reduce strike rates.

The flight cage experiments support the field results and reveal that Dark-eyed Juncos could not discriminate between clear glass and unobstructed airspace, or most of the preventative methods evaluated. Fifteen of the preventative methods produced statistically significant results with one or

more subjects (Table 1). Only four preventative methods resulted in statistically significant avoidance for all subjects. All Juncos avoided windows that were completely covered and rendered translucent by a white cloth drape, and three patterns consisting of 2.5 cm wide white cloth strips that uniformly covered the entire window. The effective patterns were: (1) a rectangular mesh forming 8 cm wide by 10 cm high openings, (2) vertical strips separated by 10 cm, and (3) horizontal strips separated by 5 cm (Table 1).

TABLE 1. Results of laboratory experiments in which Dark-eyed Juncos (*Junco hyemalis*) significantly[a] avoided preventative method.

Preventative method	Number tested	Number significantly avoiding method[a]
Large diving falcon silhouette	5	1
Barred Owl silhouette	5	1
Blinking lights around window frame	3	1
Blinking lights around hanging plant.	5	2
White cloth drape covering entire window	5	5
White cloth strips, 2.5 cm wide forming mesh sizes (cm):		
44 x 58	5	1
29 x 38	5	1
21 x 28	5	2
14 x 18	1	2
10 x 13	4	3
8 X 10	5	5
White cloth strips, 2.5 cm wide placed vertically and separated by (cm):		
10	4	4
5	4	3
White cloth strips, 2.5 cm wide placed horizontally and separated by (cm):		
10	5	3
5	4	4

[a]Binomial tests were used to determine if the results of 10 to 30 trials per subject differed significantly ($P < 0.05$) from the expected equal distribution.

DISCUSSION

Window casualties have the potential and already may be a significant mortality factor for some species of birds. My findings, reported here and elsewhere, clearly indicate that birds do not recognize glass as a barrier (Klem 1979, Klem, in press). Potential victims are the fit and unfit of abundant as well as rare, threatened, and endangered species. At the windows of one building in Europe, 54 birds were killed over a 2 mo period (Morzer Bruijns and Stwerka 1961). My records document at least 33 deaths/yr resulting from window strikes at a single dwelling, and 1 out of 2 strikes resulted in a fatality. These same data reveal that window strikes are equally lethal for small

and large species. Documenting the effects on local populations, Löhrl (1962) described the regular attrition of Swallows *(Hirundo rustica)* killed hitting a clear glass corridor until their nearby colony was abandoned. Windows increase the threat to endangered populations; Walkinshaw (1976) reported a window-killed Kirtland's Warbler *(Dendroica kirtlandii),* and Burns (pers. comm.) related another account of Kirtland's Warbler hitting and surviving a window strike. L. Kiff (pers. comm.) cited the persistent losses of Peregrine Falcons *(Falco peregrinus)* from collisions with reflective windows as a serious threat to the successful reintroduction of this species in urban environments. My survey of museum curators and individuals throughout the United States and Canada suggest greater vulnerability for those species whose activities occur on or near the ground, such as several species of thrushes, wood warblers, and finches (Klem 1979; Klem, in press).

The window hazard is likely to increase for resident and migrant birds as more and more undisturbed habitat is modified by human development and the construction of new buildings containing large expanses of glass. In addition to commercial growth stimulated by economic interests, human population trends in the U.S. show a return to rural areas (Long and DeAre 1982) resulting in increased land development and an increased threat for birds.

One annual estimate of avian mortality resulting from strikes is 3.5 million for the United States alone (Banks 1979). This figure is based on the assumption that 1 bird is killed per square mile of land per year. My findings of multiple windowkills at several man-made structures of various types in urban, suburban, and rural settings, throughout every season, and under almost every weather condition suggest this is an extremely low figure. Admittedly no less speculative, I offer an alternative based on the criteria that 1 to 10 birds are killed per building per year in the U.S. Attempting to be conservative, I used U.S. Bureau of Census (1986) data and estimated the number of U.S. buildings by assuming each housing unit (93,519,000), commercial building (3,948,000), and school (96,626) equated to 1 building each; this yields an annual windowkill toll of 97.6 to 975.6 million birds. The estimate is fundamentally speculative because it assumes U.S. buildings that kill no birds are compensated for by those that kill many. Direct evidence supporting this assumption is not available, but given known collision fatalities at single buildings, I submit that my suggestion is reasonable if not overly conservative. Moreover, compensating for man-made structures that kill no birds are buildings known to kill many but were not included in my estimate. They are corporations and businesses that have more than I structure such as those in multistory and multibuilding shopping mall complexes, schools such as colleges and universities consisting of more than 1 building, and all types of local, state, and federal government buildings.

The 98 to 976 million death toll is offered as a general order of magnitude, but still represents only 0.5 to 5.0% of the 20 billion birds estimated to compose the continental U.S. bird population after the breeding season each year (A.O.U. 1975). Banks' (1979) estimate of yearly window-kills represents 2.0% of the approximately 197 million annual bird deaths he attributes to all human activity. Other comparative yearly estimates for other human-related avian mortality range from approximately 3.5 million (2.0%) fatalities due to pollution and poisoning to 57 million (29.2%) resulting from road collisions and 120.5 million (61.5%) from hunting. My lowest estimate of annual window-kills for the U.S. exceeds all but the mortality figures for hunting, and I suspect that additional study will reveal glass panes to exact the highest toll of any human-related avian mortality.

A uniquely human concern is the guilt and anxiety felt by a growing number of the general public who discover that the windows of their houses and work place are killing birds. This concern will likely have an increasing impact on the glass industry, architectural designs, landscape planners, and the conservation community as more publicity and studies reveal the details of this mortality

factor for wild bird populations. Ironically, many aesthetic buildings housing local, state, and federal park visitor centers are literally covered with glass, and these buildings regularly kill some of the birds that the public comes to see.

Any factor that increases the density of birds near windows is known to increase strike rate (Klem, in press). Consequently, the human propensity for placing bird attractants such as feeders, watering areas, and nutritious and aesthetic vegetation in front of windows increases the hazard. Interestingly, collisions and most evidence of their occurrence are often masked by the presence of foundation plantings and the actions of scavengers, predators, and building personnel that regularly patrol and collect the unsightly dead and dying.

Elimination of bird attractants near windows will reduce or completely prevent strikes by reducing bird densities near the glass hazard. Alternatively, place attractants such as feeders within 0.3 m of the glass surface. Birds are drawn to the attractant upon arrival, and due to the close proximity of the attractant to the window, they are not able to build up enough momentum to sustain serious injury if they hit the glass upon departure.

My experimental results have revealed varied and effective methods of preventing bird strikes. Other than removing windows from man-made structures, an action taken in some instances but obviously unacceptable under most circumstances, glass panes must be completely covered if collisions are to be eliminated. Covering windows with netting is most effective when cost and aesthetic appearance are acceptable. Alternatively, glass panes must be transformed into obstacles that birds can recognize and avoid. Spiders seem to have solved similar problems using stabilimenta to make their orb webs more visible to flying birds (Eisner and Nowicki 1983). In a like manner, to successfully protect hummingbirds and the smallest passerines, windows must be uniformly covered with objects on or near the glass surface and separated by 5 to 10 cm. I found 2.5 cm cloth strips oriented vertically and separated by 10 cm must be separated by 5 cm to be as effective when oriented horizontally. The difference in the effectiveness for these two orientations may be associated with a bird's adaptive response to the placement of vertical tree trunks separated by greater distances than horizontal tree branches. These results indicate that birds in flight are more apt to give vertical objects wider clearance than horizontal ones.

For new or remodeled buildings, architects and designers are encouraged to install windows at an angle such that the pane reflects the ground instead of the surrounding habitat and sky. Preliminary observations indicate that at a single building with windows angled in at their base, birds avoid flying into an illusion of the ground, but are easily deceived by and strike reflected images of habitat and sky on windows installed in the conventional vertical position.

Single objects such as falcon silhouettes or owl decals, large eye patterns, various other pattern designs, and decoys did not reduce strike rates to a statistically significant level in my field or flight cage experiments. Many such objects are commercially available, but they fail to prevent most strikes because they cover only part of the glass and are not applied in sufficient numbers to alert the birds to the glass barrier. Glass surfaces must be uniformly covered with objects or patterns, separated by 5 to 10 cm, to effectively prevent bird strikes at windows.

My survey of museums revealed that window-kills are a valuable but largely neglected ornithological resource. Of obvious value is the availability of specimens for anatomical and plumage studies. Knowledge of geographic distribution and migration routes can be enhanced through careful documentation of window casualties (Johnson and Hudson 1976). Nisbet (1970) provided an excellent example of how similar data from television and radio tower-kills were used to study migration patterns. Man-made structures with windows are distributed worldwide in contrast

to the relatively restricted geographic distribution of towers. Moreover, where towers typically collect nocturnal migrants under adverse weather, windows kill birds in the day and night, throughout the year, and under most weather conditions. An Indigo Bunting *(Passerina cyanea)* that was banded after surviving a window collision in Canada killed itself striking the same window a year later; this account provides direct evidence of individual migrants reusing the same migratory routes from one year to the next (M. T. Butler, pers. comm.). Studies designed to band a select number of window strike survivors should be considered to further address survival rates and other migration-related questions. In general, studies of bird strikes at windows are encouraged to better understand the toll that this source of man-caused avian mortality exacts on specific species, and as an additional source of museum specimens.

ACKNOWLEDGMENTS

I am indebted and grateful to William G. George who introduced me to this study, and further stimulated my interest and concern for man-caused wildlife mortality. For their comments and suggestions I thank T. R. Anthoney, R. C. Banks, J. R. Bart, D. L. Beggs, E. H. Burtt, Jr., M. T. Butler, W. G. Dyer, A. J. Gatz, W. G. George, W. D. Klimstra, E. A. LeFebvre, L. R. Mewaldt, W. B. Quay, R. Raible, B. Valum, C. J. Veltri, G. H. Waring and F. D. Watson. I thank M. and W. G. George, R. A. Klem, H. Schramm, M. Van Tuinen, and R. Vanderjack for help in the field. I am especially grateful to J. and M. Hayward, P. Rothstein, and several museum curators and individuals who collected or provided data. I thank A. T. Tax, H. Munch, and W. E. A. Reese for translations. Financial support or materials were given by W. G. George, The Huge' Co. Inc., A. Mucci, Muhlenberg College, Pittsburgh Plate Glass Foundation, and Southern Illinois University at Carbondale. For their extensive support and interpretation I am most grateful to T. R. Anthoney, R. C. Banks, R. A. Klem, and A-M. and G. H. Waring.

LITERATURE CITED

AMERICAN ORNITHOLOGISTS' UNION. 1975. Report of the ad hoc committee on scientific and educational use of wild birds. Auk 92(Suppl.)1A-27A.

AVERY, M. L., P. F. SPRINGER, AND N. S. DAILY. 1980. Avian mortality at man-made structures: an annotated bibliographv (Revised). Washington, D.C., U.S. Fish Wildl. Serv. Spec. Sci Rep. 215:1-16.

BANKS, R. C. 1976. Reflective plate glass—a hazard to migrating birds. Bioscience 26: 414.

——. 1979. Human related mortality of birds in the United States. U.S. Fish Wildl. SerN. Spec. Sci. Rep. 215:1-16.

BLEST, A. D. 1957. The function of eyespots in the Lepidoptera. Behaviour 11:209-256.

EISNER, T., AND S. NOWICKI. 1983. Spider web protection through visual advertisement: role of the stabilimentum. Science 219:185-187.

JOHNSON, R. E., AND G. E. HUDSON. 1976. Bird mortality at a glassed-in walkway in Washington state. Western Birds 7:99-107.

KLEM, D., JR. 1979. Biology of collisions between birds and windows. Ph.D. dissertation Carbondale, Southern Illinois Univ.

——. 1981. Avian predators hunting birds near windows. Proc. Pennsylvania Acad. Sci. 55:90-92.

——. In press. Bi rd-window collisions. Wilson Bull.

LÖHRL, H. 1962. Vogelvernichtung durch moderne glaswände. Kosmos 5:191-194.

LONG, L., AND D. DEARE. 1982. Repopulating the countryside: a 1980 census trend. Science 217:1111-1116.

MORZER BRUIJNS, M. F., AND L. J. STWERKA. 1961. Het doodvliegenvan vogels tegen ramen. De Levende Natuur, 64:253-257.

NISBET, I. C. T. 1970. Autumn migration of the Blackpoll Warbler: evidence for long flight provided by regional survey. Bird-Banding 41:207-240.

SIEGEL, S. 1956. Nonparametric statistics for the behavioral sciences, New York, McGraw-Hill.

SOULE, M. E., Ed. 1986. Conservation biology. Sunderland, Massachusetts, Sinauer Associates, Inc.

TOWNSEND, C. W. 1931. Tragedies among Yellow- billed Cuckoos. Auk 48:602.

U.S. BUREAU OF THE CENSUS. 1986. Statistical Abstracts of the United States: 1987. Washington, D.C.

WALKINSHAW, L. R. 1976. A Kirtland's Warbler life history. Am. Birds 30:773.

WEIR, R. D. 1976. Annotated bibliography of bird kills at man-made obstacles: a review of the state of art and solutions. Ottawa, Ontario, Dept. Fish. & Environ.., Canadian Wildl. Serv.

A Summary and Comparison of Bird Mortality from Anthropogenic Causes with an Emphasis on Collisions[1]

Wallace P. Erickson,[2,3] Gregory D. Johnson,[2] and David P. Young Jr.[2]

Abstract

We estimate that from 500 million to possibly over 1 billion birds are killed annually in the United States due to anthropogenic sources including collisions with human-made structures such as vehicles, buildings and windows, power lines, communication towers, and wind turbines; electrocutions; oil spills and other contaminants; pesticides; cat predation; and commercial fishing by-catch. Many of the deaths from these sources would be considered unlawful take under federal laws such as the Endangered Species Act, Migratory Bird Treaty Act, and the Bald and Golden Eagle Protection Act. In this paper, we summarize this literature and provide the basis for the mortality projections for many of the apparent significant sources. Most of the mortality projections are based on small sample sizes, and on studies typically lacking adjustments for scavenging and searcher efficiency biases. Although the estimates for each source often range by an order of magnitude, the cumulative mortality from all these sources continues to be a concern.

Key Words: avian mortality, avian fatalities, collisions, communication towers, contaminants, electrocutions, fishing by-catch, power lines, vehicles, wind turbines.

Introduction

All taxonomic groups of birds are subjected to significant human-caused mortality. Most of the anthropogenic-caused bird mortality would be considered unlawful take under the Migratory Bird Treaty Act, Endangered Species Act, and Bald and Golden Eagle Protection Act. The recently well-publicized prosecution of a utility for Golden Eagle (*Aquila chrysaetos*) electrocutions in Colorado by the United States Fish and Wildlife Service has increased the awareness of these issues (Manville this volume a). Collisions with artificial structures are a significant and well-documented source of bird mortality. Bird collisions with artificial structures and associated fatalities have been documented in the United States (US) since the late 1880s (Crawford and Engstrom 2000). A large amount of published and unpublished literature exists on avian collisions with artificial structures and vehicles. Bird mortality associated with pesticides, oil spills, oil pools, and other contaminant sources have also received significant attention. Domestic and feral cats have also been considered a major source of anthropogenic-caused mortality with estimates near 100 million annual bird deaths. However, calculating accurate numbers of bird fatalities associated with any of these sources is difficult due to limitations in the scope of most mortality studies, as compared to the extensive distribution and extent of these sources. Some individual studies have been well designed to obtain accurate fatality estimates for the particular structure(s) investigated (e.g., Kemper 1996, Johnson et al. 2002); however, most studies that are available for making these estimates lack standardized methods for searching, and often do not consider sources of bias, such as scavenging and searcher efficiency.

Many of the studies are limited to documenting avian collisions at a particular season or location. For example, many of the studies are limited to fall migration periods. Furthermore, many of the studies were conducted in response to suspected or actual large mortality events, and focus on areas where the number of fatalities may be unusually high. For example, many power line studies involved monitoring fatalities associated with lines near wetlands with high waterfowl use. In many cases, fatality estimates derived from data reported in the available literature would most likely be an over-estimate of the true mortality. Estimating the annual fatality rate for any of these sources requires a random or at least representative sample of experimental units (e.g., buildings, communication towers, miles of road, number of agricultural fields) with information replicated across time, but due to obvious logistical and financial constraints, a large representative sample of experimental units for each source has not been studied.

We did not attempt to develop our own estimates of avian mortality from sources other than wind turbines

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[1]A version of this paper was presented at the **Third International Partners in Flight Conference, March 20-24, 2002, Asilomar Conference Grounds, California**.

[2]Western EcoSystems Technology, Inc., 2003 Central Ave., Cheyenne, WY, USA. 82001.

[3]Corresponding author: E-mail: werickson@west-inc.com.

due to the lack of standardized information. We feel that the available data cannot be used to make projections based on averages of individual estimates. Instead, we have updated previous estimates provided in the literature based on increases in the number (e.g., buildings) or extent of collision sources. Although the many difficulties in making fatality projections is widely recognized, the shear magnitude of these projections should continue to bring an awareness and concern to anthropogenic-caused bird mortality.

Sources of Biases in Estimating Fatality Rates

Determining the extent of wildlife mortality due to environmental perturbations such as oil spills or due to collisions with structures such as power lines, buildings, communication towers, or wind plants is a difficult sampling and estimation problem (Erickson et al. 2000a, 2001). Biases associated with observer detection and scavenging rates can lead to biased mortality estimates (Morrison 2002). Observers conducting searches for carcasses often may not detect some of the carcasses for various reasons including dense vegetative cover, size of carcass and cryptic coloration of the carcasses. During fatality studies at the Buffalo Ridge wind plant in southwest Minnesota, the proportion of carcasses detected by observers, (i.e., searcher efficiency rates) for small birds (e.g., most passerines) was estimated at 30 percent when averaged across several habitat types (e.g., plowed field, corn, wetland, CRP/grassland) and across spring, summer and fall seasons (Johnson et al. 2002). In contrast, searcher efficiency rates for small birds at the Foote Creek Rim wind plant, Wyoming in short grass prairie habitat was 57 percent (Young et al. 2003). Searcher efficiency rates for large birds (e.g., waterfowl and raptors) were 49 percent on average at Buffalo Ridge, but over 90 percent at Foote Creek Rim. Similar protocols for searching (transect widths, etc.) were used at both sites. Comparisons of fatality rates at Foote Creek Rim and Buffalo Ridge that unadjusted for searcher efficiency would be very misleading.

Estimated disappearance or scavenger removal rates vary significantly in the literature. Nearly 80 percent (79.2) of the chicks placed in a mixed grazed pasture were removed within 24 hr of being placed (Wobeser and Wobeser 1992). In Maryland, approximately 75 percent of 78 trial carcasses placed in agricultural fields were removed in the first 24 hr (Balcomb 1986). During a study at a TV tower in Florida, 93 percent of 157 birds purposely placed underneath the tower at dusk to monitor predation were partially or completely removed by the next morning (Crawford 1971). In France, Pain (1991) estimated duck carcasses lasted an average of 1.5 d in open habitats, whereas those concealed by vegetation or those in water lasted between 3.3 and 7.6 d. In one orchard during this study, scavengers removed all 25 of the placed carcasses within 24 hr, with lower rates in the other orchards studied. At the Vansycle wind plant in Oregon, small carcasses or evidence of the carcass (e.g., feather spot) lasted an average of 15.0 d, and large carcasses lasted on average longer than 28 d (Erickson et al. 2000b). At the Buffalo Ridge wind plant, small carcasses persisted an average of 4.7 d, whereas small birds at Foote Creek Rim persisted 12.2 d. Disappearance rates also likely vary by species or avian group. For example, it is speculated that raptor carcasses last longer than other large bird carcasses such as game birds and waterfowl, although limited empirical data exist to test this hypothesis.

Carcass detection rates and scavenging rates do vary among sites, habitats, seasons and sizes of birds. Comparison of fatality rates that are not adjusted for these two primary sources of bias can be very misleading. Differences in observed fatality rates may only reflect true differences in scavenger densities or carcass detection rates. Many, if not most of the studies of bird mortality we present below, do not account for the biases described above. The following sections provide a review of studies of mortality for collision sources such as power lines, buildings and windows, communication towers and wind turbines.

Collision Mortality

Avian Mortality Due to Collisions with Automobiles, Trains, and Airplanes

Study examples

Although several studies have been conducted in Europe (e.g., Finnis 1960, Hodson 1962, Dunthorn and Errington 1964, Hodson and Snow 1965, Hugues 1996), we found relatively few documents that reported vehicle-related avian mortality in the United States. In Illinois, Decker (1987) traversed a 4.4-mile (7 km) stretch of road daily and estimated mortality at 33 birds per mile per year (21 birds/km/year). The most common fatalities were passerines or other small birds, including Yellow-billed Cuckoo (*Coccyzus americanus*), Blue Jay (*Cyanocitta cristata*), Red-winged Blackbird (*Agelaius phoeniceus*), and Indigo Bunting (*Passerina cyanea*). In Ontario, Canada, Ashley and Robinson (1996) searched a 2.2 mile (3.6 km) stretch of road located near wetlands three days a week and calculated that 223 birds were killed per mile per year (139 birds/km/year), most of which were passerines. No adjustments were made for searcher efficiency or scavenger removal in either of these studies.

From 1969 to 1975, Case (1978) searched the entire length of Interstate 80 in Nebraska (458 miles, 732 km) and documented a total of 7,195 Ring-necked Pheasant (*Phasianus colchicus*) vehicle collision fatalities. Based on finding 562 dead ducks over a 10-year period, Sargeant (1981) estimated that vehicles killed an average of 13,500 ducks each year in the prairie pothole regions of North and South Dakota. Mean annual mortality of ducks was estimated to be 0.250 ducks per mile (0.156 ducks/km) of interstate, 0.008 ducks per mile (0.005 ducks/km) of unsurfaced roads, and 0.042 ducks per mile (0.026 ducks/km) for all road types combined. Although the number of fatalities appears high, it was estimated to represent less than 0.2 percent of the breeding population in the study area. Much lower mortality was documented during other studies. McClure (1951) documented only four road-killed ducks while driving 76,250 miles (122,000 km) of road in Nebraska. In Minnesota, Sargeant and Forbes (1973) found only three road-killed ducks along 17 miles (27 km) of roads driven almost daily for an 18-month period. Raptors also appear susceptible to vehicle collisions in some areas. Based on driving surveys over a 10-year period in New Jersey, Loos and Kerlinger (1993) estimated that 25 raptors were killed per year within a 90-mile (145 km) survey route. Most of the fatalities were owls; however, six species of hawks were also found among road fatalities.

Annual mortality predictions

Banks (1979) summarized several studies and reported estimates of avian fatality rates ranging from 2.7 to 6.1 deaths per mile of road per year to 60 to 144 bird fatalities per mile per year. From U.S. studies reported in Banks (1979), use of the minimum (2.7) and maximum (96.25) reported values for bird deaths per mile yields estimates of 10.7 million to 380 million annual bird deaths on U.S. roads. Banks (1979) estimated total annual avian road mortality to be 57.2 million. This figure was derived from the estimate of 15.1 bird fatalities per mile reported by Hodson and Snow (1965), who conducted a fairly extensive study in England, although no scavenging or searcher efficiency bias was considered which would result in an underestimate of true fatality rates. The U.S. Census Bureau (Statistical Abstract of the United States 1999) estimated 3,944,597 miles of road in the US in 1997. Using this number to update Banks' estimate yields a 1997 estimate of approximately 60 million avian fatalities on U.S. roadways annually. The number of registered vehicles has increased 35 percent from 1980 to 1998 alone, so an alternative estimate would be 1.35 times 60 million, or approximately 80 million avian fatalities. It is believed that some of the mortality observed along roads is actually caused by collisions with adjacent power and telephone lines (C.J. Ralph, pers. comm.).

Although most avian fatalities caused by vehicles occur on roadways, avian collisions also occur with trains (Spencer 1965) and airplanes. Avian collisions with airplanes present a significant hazard to both military and commercial aircraft. The Federal Aviation Administration (FAA) keeps records of avian collision strikes involving aircraft in the US. In 1998, the U.S. Air Force reported over 3,500 bird strikes by planes, and it is estimated that civil aircraft strike over 25,000 birds per year. Data collected from 1990 to 1999 indicate that gulls (31 percent), waterfowl (31 percent) and raptors (15 percent) comprised 77 percent of the reported bird strikes causing damage (Bird Strike Committee USA 2000). No estimates for train-caused avian mortality were found in the literature. It is likely that train collisions also result in several thousand bird deaths annually in the United States.

Avian Mortality Due to Collisions with Buildings and Windows

Study examples

Numerous studies have documented extensive avian collision mortality associated with buildings and similar structures such as smokestacks or monuments. Fatalities associated with buildings are usually the result of collisions with tall buildings and collisions with windows at residential houses. Studies may be divided into two categories, studies of short-term or episodic mortality events, and longer-term studies. Some mortality events at tall buildings have involved extensive numbers of birds. At one oil flare stack in Alberta, 1,393 dead birds comprised of 24 species of passerines were found over a 2-day period in May 1980 (Bjorge 1987). Over a 3-day period in October 1964, Case et al. (1965) searched several buildings in Florida and recovered 4,707 dead birds, most of which were passerines. Also in Florida, Maehr et al. (1983) searched the base of four smokestacks over a 2-day period in September and recovered 1,265 dead passerines. The authors estimated that 5,000 birds might have collided with the structures during this period. In the fall of 1970, 707 dead birds were documented below the Empire State Building in New York (Bagg 1971). Extensive numbers of nocturnal migrant fatalities have also been documented at the Washington Monument in Washington, D.C. (Overing 1936). From October 5-8, 1954, 9,495 dead birds (mostly passerines) were found at 25 tall buildings in the eastern and southern US following a cold front during fall migration, and it was estimated that 106,804 birds were actually killed (Johnston and Haines 1957).

Several long-term studies have documented the chronic nature of collision mortality associated with some buildings (Erickson et al. 2001). Over a 3-year period in Toronto, Ontario, Ogden (1996) counted 5,454 dead

birds at 54 tall glass buildings and estimated that 733 birds (mostly passerines) were killed per building per year. Following nights with inclement weather conditions, Taylor and Kershner (1986) searched one building in Florida from 1970 to 1981 and documented 5,046 avian fatalities comprised of 62 species, the majority of which were passerines. Two smokestacks in Citrus County, Florida were searched five times per week from 1982 to 1986, and 2,301 dead birds were found (Maehr and Smith 1988). From this, the authors estimated that 541.4 birds were killed per year. Fatalities included 50 species, most of which were neotropical migrant passerines. Daily searches of two smokestacks in Ontario, Canada over a 4-year period yielded 8,531 dead birds. Again, most of these were passerines (Weir 1976).

Klem (1990) searched two houses in Illinois and New York daily from 1974 to 1986. A total of 100 dead birds were found at the houses, and the author estimated that 55 percent of window collisions result in death. Over the 1989-1990 winter, 5,500 residential houses in the U.S. were searched for dead birds using a standardized procedure, and a total of 995 dead birds were found (Dunn 1993). The author estimated that an average of 0.85 birds are killed per house each winter based on actual mortality ranging from 0.65 to 7.7 birds per house per year. The fatalities were comprised of 66 species, most of which were passerines commonly found at feeders during the winter.

Annual mortality predictions

In 1995 there were an estimated 4,579,000 commercial buildings (warehouse, religious/worship, public assembly, offices, mercantile/services, lodging, health care, food sales, education) in the United States (Statistical Abstract of the United States 1999). Klem (1990) reported there were 93.5 million residential houses in 1986. Due to the large number of structures in this class, and only a few good studies, it is difficult to obtain very accurate fatality estimates for the US. Most of the building and window collision data come from studies of known or suspected problem structures. Accurately predicting the number of building-related avian fatalities would require random selection of numerous buildings of all types and sizes, followed by long-term standardized and systematic searches for dead birds.

Banks (1979) acknowledged a lack of information on building and window collision mortality, and estimated 3.5 million avian fatalities per year based on an arbitrary estimate of 1 bird fatality per square mile in the US. An estimate of 97.6 to 976 million bird deaths per year in the U.S. due to collisions with windows was based on an estimated 1 to 10 bird deaths per structure per year from a fatality study in New York (Klem 1990).

Avian Mortality Due to Collisions with High Tension Lines

Study examples

Concern over avian collisions with high-tension lines has existed at least since 1876, when Coues (1876) counted approximately 100 avian carcasses (primarily Horned Larks (*Eremophila alpestris*) beneath a 3-mile long (4.8 km) section of telegraph wire between Denver, Colorado, and Cheyenne, Wyoming. Since then, there have been numerous studies of power line collisions involving birds. Faanes (1987) searched 6 miles (9.6 km) of power lines in North Dakota in the spring and fall of 1977 and 1978. Based on a total of 633 dead birds found, he estimated that 200 avian fatalities per mile per year (125 birds/km/yr) were occurring at those sites. The power lines included in the study were located near wetlands or lakes and most of the fatalities consisted of waterbirds (46 percent) and waterfowl (26 percent), followed by shorebirds (8 percent), and passerines (5 percent).

For some types of birds, power line collisions appear to be a significant source of mortality. Waterfowl band recovery data collected prior to 1967 indicated that powerline strikes were responsible for 65 percent of the collision fatalities involving 3,015 banded birds (Stout 1967). Of 75 Trumpeter Swan (*Cygnus buccinator*) deaths recorded from 1958 to 1973, 19 percent of the fatalities were due to powerline collisions (Weaver and St. Ores 1974). During a 2-year study of Mute Swans (*C. olor*) in Rhode Island, Willey (1968) found that 26.7 percent of adult fatalities were due to collisions, mostly with powerlines.

Annual mortality predictions

The U.S. electrical energy system includes more than 500,000 miles (800,000 km) of bulk transmission lines (Edison Electric Institute 2000). Estimates for the total length of distribution lines (power lines to residences and businesses) in the US could not be found in the literature, but are far greater than for bulk transmission lines. Estimates of avian fatalities due to collisions with high-tension lines are lacking due to minimal monitoring efforts on a large-scale basis. As with most other sources of collision mortality, most monitoring and/or studies are conducted in response to a known or perceived problem, and few data have been collected at randomly-chosen sites. Based on the limited studies, waterfowl including ducks, geese, swans, cranes, and shorebirds appear to be most susceptible to collisions when powerlines are located near wetlands. In upland

habitats away from wetlands, raptors and passerines appear most susceptible to collision.

In the Netherlands, where approximately 2,875 miles (4,600 km) of high-tension lines are present, Koops (1987) estimated that approximately 750,000 to 1 million birds are killed annually by collisions based on variation in extrapolation made in three other Netherlands studies. Estimates in all three studies were in the same order of magnitude. The latter study estimated (unadjusted for scavenging and searcher efficiency) 113 fatalities per km of high tension line in grasslands, 58 fatalities per km of high tension line in agricultural lands, and 489 fatalities per km of high tension line near river crossings. We use the mean estimate (adjusted for scavenging and searcher efficiency bias) of 750,000/2,875 = 261/mile of high tension line. Extrapolating the mid-range of this estimate to the 500,000 miles (800,000 km) of bulk transmission lines in the United States would lead to a fatality estimate of approximately 130 million birds per year. Given the large, but unknown number of miles of power and other high tension lines in the U.S., and the lack of standardized data in the U.S., this estimate may be off by an order of magnitude or more.

Avian Mortality Due to Collisions with Communication Towers

Study examples

Substantial concern over the recent proliferation of communication towers in the U.S. has arisen in response to large fatality events, such as an estimated kill of 5,000 to 10,000 birds, mostly Lapland Longspurs (*Calcarius lapponicus*), at 3 associated communication towers and a natural gas pumping facility in western Kansas on the night of January 22, 1998 (Evans 1998). Large, single-night fatality events are not new. Kemper (1996) counted and identified species for over 12,000 birds killed one night in 1963 at a television tower in Wisconsin. As a result of this concern, avian collision mortality associated with communication towers has received more study and review than other sources of collision mortality, with the possible exception of wind turbines. During our review we located numerous studies covering avian collision mortality with communication towers in 25 states. The vast majority of the studies were one-day searches at single towers following nights of substantial avian mortality. Most avian fatalities at communication towers involve nocturnal migrant passerines, especially warblers, vireos, and thrushes.

Erickson et al. (2001) reported on 17 studies where collision mortality was measured for periods of time ranging from one to 38 years. For studies conducted over a period of at least two years, with searches conducted on a daily or almost daily basis, the estimated mean number of annual collisions per tower ranged from approximately 82 birds per year at an 825-ft (250-m) tall television tower in Alabama (Bierly 1968, 1969, 1972; Remy 1974, 1975; Cooley 1977) to 3,199 birds per year at a 1,000-ft (305-m) tower in Eau Claire, Wisconsin (Kemper 1996). Very few of these studies measured scavenger removal and searcher efficiency. The research at Eau Claire, Wisconsin, was the longest study conducted at any one tower and covered the period from 1957 to 1994 (38 years). Two other continuous studies at individual communication towers include a study from 1960 to 1997 (37 years) at a 1,368-ft (417-m) tower in Nashville, Tennessee (Nehring 2000), and another study that took place at a 1,010-ft (308-m) tower from October 1955 to December 1983 (28 years) at Tall Timbers Research Station in Tallahassee, Florida (Crawford and Engstrom 2000). At the Tennessee tower, 19,880 fatalities were recovered over the 37-year period. At the Florida tower, 1,517 birds on average were killed per year.

Annual mortality predictions

Based on the July 2002 statistics from the Federal Communication Commission's (FCC) Antenna Structure Registry Database (FCC 2002), more than 138,000 towers were listed with the Commission, of which some 106,000 were lighted. Since an undetermined number of towers are not registered with the FCC, and the number of new towers are increasing at a high rate (Manville this volume a), the total number of communication towers may be as high or higher than 200,000. Numerous types of towers are being built, including radio, television, cellular, microwave, paging, messaging, open video, public safety, wireless data, government dispatch, and emergency broadcast towers (Manville this volume a). Due to the recent proliferation of cellular phones and the advent of digital television, approximately 5,000 to 10,000 new towers are being added each year (6-8 percent increase annually). Some have estimated there will be a total of 600,000 towers in the United States within the next 10 years, creating a potentially catastrophic impact on avian migrants (M. Manville, pers. comm.). Avian mortality appears to increase with tower height. Taller towers also tend to have more guy wires and more lights, often more solid or pulsating red lights, which may increase the potential for collision mortality.

Most lighted towers are lit due to FAA pilot warning regulations. On foggy or low cloud-ceiling nights, these lighted towers appear to attract neotropical nocturnal migrants (Manville 2000, Kerlinger 2000), increasing the risk of collision. Lighting appears to be the single most critical attractant, and preliminary research indicates that solid and pulsating red lights seem to be more attractive to birds at night during inclement

weather conditions than are white strobe lights. It is speculated that the birds are attracted to the lighted towers, become disoriented and fly around them in a spiral, colliding with the tower, the guy wires, other birds, or falling to the ground in exhaustion (Larkin and Frase 1988, M. Manville, pers. comm.).

There are very few long-term studies of avian mortality at communication towers, although there are concerted efforts by both the industry and other interested parties to begin collecting standardized data and using standardized metrics following the methods and metrics recommended and used at many wind power plants (Anderson et al. 1999). Currently, much of the published and unpublished information regarding avian fatalities at communication towers is based on single observations of carcasses found at the base of the towers (Erickson et al. 2001). Based on estimates of Banks (1979) and models developed by Tall Timber Research and Bill Evans (M. Manville, pers. comm.), conservative estimates range from 4 million to 5 million avian fatalities per year (Manville this volume a). These estimates could be off by an order of magnitude, especially as the number of towers increases at a high rate each year (Manville this volume a). Further studies are obviously needed to ascertain the true impact.

Avian Mortality Due to Collisions with Wind Turbines

Study examples

Many of the early studies of bird mortality at wind plants involved examining impacts associated with single, large experimental turbines. The first study took place in Sandusky, Ohio, where a single large turbine was monitored for avian mortality during four migratory seasons. Two dead birds were found during this period (Gauthreaux 1994). Two large experimental turbines and a meteorological tower in Wyoming were monitored for avian mortality in the early 1980s. Twenty-five fatalities were found over a one-year period, most of them involving passerines that had collided with guy wires on the meteorological tower (U.S. Bureau of Reclamation 1984). At a single, 60-m tower wind turbine in Solano County, California, seven fatalities were documented from September 1982 to January 1983, and the total fatality estimate with adjustments for scavenger removal and searcher efficiency was estimated at 54 birds (Byrne 1983, 1985).

Most of the concern over bird mortality from wind turbines began at one of the first large-scale wind energy developments in the US In response to several reported incidents of avian collisions, the California Energy Commission (CEC) obtained data on bird strikes at the Altamont and Tehachapi wind plants in California through interviews and review of unpublished data collected over a 4-year period from 1984 to 1988 (CEC 1989). This study documented 108 raptor fatalities of seven species. Collisions with wind plant structures accounted for most of the avian fatalities (67 percent), including 26 Golden Eagles and 20 Red-tailed Hawks (*Buteo jamaicensis*), while collision and electrocutions associated with power lines comprised the majority of the other fatalities. Several subsequent studies were initiated to further examine fatalities at California wind plants. Many of these studies have been conducted at Altamont Pass, where more than 5,000 turbines exist within the WRA. In general, these studies focused on obtaining raptor fatality estimates with other bird fatalities recorded coincidentally. An early 2-year study documented 182 bird deaths on study plots, 68 percent of which were raptors and 26 percent of which were passerines. The most common raptor fatalities were Red-tailed Hawk (36 percent), American Kestrel (*Falco sparvarius*) (13 percent), and Golden Eagle (11 percent). Causes of raptor mortality included collisions with turbines (55 percent), electrocutions (8 percent), and wire collisions (11 percent) (Orloff and Flannery 1992). Based on the number of dead birds found, the authors estimated that as many as 567 raptors may have died over the 2-year period due to collision with wind turbines. Further investigations at Altamont continued to document levels of raptor mortality sufficient to cause concern among wildlife agencies and others (Orloff and Flannery 1992, 1996; Howell 1997).

Raptor mortality at other older wind plants in California is apparently less that what has been observed at Altamont. Researchers estimated 6,800 birds were killed annually at the San Gorgonio wind facility (more than 3000 turbines) based on 38 dead birds found while monitoring nocturnal migrants at a small sample of turbines. McCrary et al. (1983, 1984) estimated that 69 million birds pass through the Coachella Valley annually during migration; 32 million in the spring and 37 million in the fall. The 38 avian fatalities were comprised of 25 species, including 15 passerines, seven waterfowl, two shorebirds, and one raptor. Considering the high number of passerines migrating through the area relative to the number of passerine fatalities, the authors concluded that this level of mortality was biologically insignificant (McCrary et al. 1986), although the mortality estimates were based on a small sample size. During a more recent study at San Gorgonio, (Anderson, pers. comm.) documented 58 fatalities near wind turbines, including fifteen doves (mostly *Columba livia*), five waterfowl, seven rails (mostly American Coot [*Fulica americana*]), seven passerines, four gulls, three owls, two ravens, one diurnal raptor, one egret, and eleven unidentified birds. The waterfowl, rail and shorebird mortality generally occurred when water was

present in the vicinity of the wind resource area, attracting large numbers of waterfowl and shorebirds.

The high levels of raptor mortality associated with the Altamont wind plant has not been documented at newer wind plants constructed in other states (*table 1*). We discuss three wind resource areas that have been monitored for mortality and have included adjustments for scavenging and searcher efficiency bias (Osborn et al. 2000, Johnson et al. 2002, Young et al. 2003, Erickson et al. 2000b), although other studies listed in *table 1* include Erickson et al. 2003a and 2003b, Howe et al. 2002, Nicholson 2003 and Johnson et al. 2002.

Several studies have been conducted at the Buffalo Ridge wind resource area, which is located an agricultural landscape in southwestern Minnesota. At the 73-turbine Phase I wind plant, eight collision fatalities were documented during the initial two-year period of operation (Osborn et al. 2000). The fatalities consisted of one Ruddy Duck (*Oxyura jamaicensis*), one Franklin's Gull (*Larus pipixcan*), one Yellow-bellied Sapsucker (*Sphyrapicus varius*), and four passerines. The estimated total number of annual fatalities for the entire wind plant was 36, equivalent to an annual mean of 0.49 collisions per turbine per year. A more extensive study of this wind plant plus two additional wind plants on Buffalo Ridge totaling over 350 turbines was conducted from 1996 through 1999. Total annual mortality was estimated to average 2.8 birds per turbine based on the 55 fatalities found during the study. Only one raptor, a red-tailed hawk, was found during the 4-year monitoring period. Most of the fatalities were passerines (76.4 percent), followed by waterfowl (9.1 percent), waterbirds and upland gamebirds (5.5 percent each). Many of the fatalities documented were nocturnal migrants (Johnson et al. 2002). Radar studies at Buffalo Ridge (Hawrot and Hanowski 1997) indicate that as many as 3.5 million birds per year may migrate over the wind development area (Johnson et al. 2002). The two largest single mortality events reported at a

Table 1–*Estimates of avian collision mortality by wind projects.*

Location of study[1]	No. turbines	No. MW	No. birds/ turbine/year	No. birds/ MW/year	No. raptors /turbine/year	No. raptors /MW/year
West (excluding California)						
Stateline, Oregon/Washington	454	300	1.69	2.56	0.053	0.080
Vansycle, Oregon	38	25	0.63	0.96	0.000	0.000
Klondike, Oregon	16	24	1.42	0.95	0.000	0.000
Nine Canyon, Washington	37	48	3.59	2.76	0.065	0.050
Foote Creek Rim, Wyoming	105	68	1.50	2.34	0.035	0.053
Subtotal	650	465	1.71	2.40	0.044	0.068
Upper Midwest						
Wisconsin (MG&E and PSC)	31	20	1.30	1.97	0.000	0.000
Buffalo Ridge, Minnesota	354	233	2.86	4.21	0.002	0.008
Subtotal	386	254	2.73	4.03	0.002	0.008
East						
Buffalo Mountain, Tennessee	3	2	7.70	11.67	0.000	0.000
Grand Total	1039	721	2.11	3.04	0.029	0.045
California (older projects)						
Altamont, California	~5400	548	na[2]	na	0.100	na
Montezuma Hills, California	600	60	na	na	0.048	na
San Gorgonio, California	~2900	300	2.31	na	0.010	na
Subtotal	~8900	878	na	na	0.067	na

Total fatality projections	Overall	Outside California
Projected annual bird fatalities[3]	20,000-37,000	9200
Raptors[4]	933	195

[1]We excluded studies of 4 small project sites in Vermont, Pennsylvania, Colorado, and Iowa that were conducted short-term and/or did not include adjustments for scavenging and searcher efficiency bias.
[2]Not available; data on scavenging or searcher efficiency or average MW of study turbines not available
[3]The per turbine/year and per MW/year estimates applied to the number of MW in U.S. at the end of 2003
[4]Based on the per turbine estimate in California (11,500 turbines) and the per MW basis outside California

U.S. wind plant were fourteen spring migrant passerines at two turbines at the Buffalo Ridge, Minnesota wind plant on one night and approximately 30 spring migrant passerines at a floodlit substation and nearby turbines in West Virginia on one night.

At the Foote Creek Rim wind plant located in Carbon County, Wyoming within native grassland-steppe and shrub-steppe habitats, total mortality associated with the 69 turbines and 5 meteorological towers was estimated to be approximately 143 birds per year, based on the 122 collision fatalities actually found during the first three years of operation (Young et al. 2003). Mean annual mortality was estimated to be 1.5 birds per turbine and 0.03 raptors per turbine per year. Of the 122 fatalities found during the study, raptors comprised only 4.0 percent, whereas passerines comprised 90.2 percent. Furthermore, while many of the fatalities at this location were nocturnal migrant passerines, the largest number of carcasses detected at a turbine during one search was two, suggesting no large mortality events of nocturnal migrants have occurred at this site.

At a 38-turbine wind plant completed on Vansycle Ridge, Oregon, which is located in an agricultural landscape, 12 avian fatalities were located during the first year of operation (Erickson et al. 2000b). The casualties were comprised of at least six species, and most of the fatalities (58 percent) were passerines. Total estimated mortality adjusted for scavenging and observer detection rate estimates, was 24 birds per year, or 0.63 birds per turbine per year. No raptors were among the fatalities (Erickson et al. 2000b).

We are unaware of any studies that directly compare communication tower mortality to wind turbine mortality; although, we do have limited information on guyed meteorological tower mortality compared with wind turbine mortality at the Foote Creek Rim, Wyoming wind plant. At this site searches of both wind turbines (600-kW, approximately 200-ft (60-m) towers) were conducted and guyed met towers (200 ft (60 m) in height) once every 28-d during the study. During this period of study, the met towers had estimates of 8.1 bird fatalities per tower per year, whereas the turbines had estimates of 1.5 bird fatalities per turbine per year (Young et al. 2003).

Annual mortality predictions

The average number of avian collision fatalities per turbine and per MW (Megawatt) are 2.11 and 3.04 per year, respectively. There were approximately 17,500 turbines and 6,374 MW of installed wind generation capacity at the end of 2003 in the United States, with approximately 6,000 turbines and 4,331 MW outside California. Therefore, on average, we calculate approximately 20,000 (3.04 times 6374 MW) to 37,000 (2.11 times 17,500 turbines) die annually from collisions with wind turbines in the United States. We estimate approximately 9,200 birds will die annually outside California from the 4331 MW of installed wind generation capacity (2003). This extrapolation assumes fatality rates observed at wind projects that have been studied are representative of rates at wind projects not studied. Fatality estimates for all birds are generally not available at most old projects in California, and for all birds and raptors from Texas and Iowa, two states with significant wind development.

Because much attention has been given to the issue of raptor/wind power interaction, we also developed separate fatality estimates for raptors. Estimates of raptor fatalities per turbine per year from individual studies through 2001 (Erickson et al. 2001) ranged from 0 at the Vansycle, Oregon; Searsburg, Vermont; Ponnequin, Colorado; Somerset County, Pennsylvania; and Buffalo Ridge, Minnesota, Phase II and Phase III sites, to 0.10 per turbine per year at the Altamont, California site (C. Thelander, pers. comm.). Based on these statistics, we estimate 933 raptors are killed annually (2003) by turbines in the United States, with approximately 80 percent of the raptor mortality occurring at the older projects in California. We project raptor mortality at wind plants outside California to be 195 per year (2003) based on relatively small number of raptors found at Buffalo Ridge Minnesota (Johnson et al. 2002), Foote Creek Rim Wyoming (Young et al. 2003), Stateline Oregon and Washington (Erickson et al. 2003a), and Nine Canyon Washington (Erickson et al. 2003b).

Other Non-collision Related Sources of Bird Mortality

The previous sections have focused on collision-related sources of bird mortality. We will now discuss in much less detail other significant sources of bird mortality which include oil spills, oil pools, cat predation, pesticides and other contaminants, electrocutions and fishing by-catch. The latter two sources are covered in more detail in Manville (this volume a, this volume b). Hunting is another obvious source of bird mortality, but since it is a permitted source, we do not discuss it.

Pesticides

Pesticides are a significant source of bird mortality in the US as well as other countries (Pimentel et al. 1991; Mineau, this volume). Large die-offs of Swainson's Hawks (*Buteo swainsoni*) were observed in Argentina due to exposure to the pesticide monocrotophos in 1996 (Di Silvestro 1996). Approximately 160 million acres of cropland are treated with pesticides each year

in the US (Pimentel et al. 1991) using data collected in the 1980s and 1990s. It has been estimated that approximately 67 million birds die annually in the US due to pesticides (Pimental et al. 1991). This estimate is based on the assumption that 10 percent of the estimated 672 million birds exposed to pesticides die each year. This estimate may be conservative, since the empirical data on bird mortality at crop fields is reported as 0.1 to 3.6 per acre (Mineau 1988). Lawn, turf, golf course and other pesticide uses were not included in this estimate.

Oil Spills

Oil spills can be a significant source of bird mortality, but the occurrence of spills and the effect and are obviously difficult to predict. Over 30,000 bird carcasses were recovered, including 250 Bald Eagles (*Haliaeetus leucocephalus*) following the 1989 Exxon Valdez oil spill in Prince William Sound Alaska, but between 100,000 and 300,000 birds of all species were estimated to have died (Piatt et al. 1990). Flint et al. (1999) conservatively estimated over 1750 birds died as the result of the M/V Citrus spill near St. Paul Island, Alaska. Small spills or chronic oiling is much less publicized, yet possibly a significant source of seabird mortality (Burger 1993). Estimates of annual mortality based on counting oiled corpses on beaches from small or chronic oiling have ranged from less than 0.01 per km of shoreline to 3.68 per km. Many oiled birds which die at sea are never found on beaches. Considering the US, including the island territories, has approximately 90,000 miles of marine tidal shoreline, annual bird mortality from chronic oiling may easily be in the 10,000 to 100,000 range.

Oil Pits

Man-made pits associated with oil and gas development are another well-documented source of bird mortality. Esmoil (1995) found 282 dead birds during weekly sampling of 35 oil pits in 1989, and 334 dead birds during weekly sampling of 53 pits in 1990. The largest affected taxonomic group was passerines (41 percent). Banks (1979), based on estimates made for the San Joaquin Valley in the early 1970s, conservatively estimated 1.5 million birds die annually due to these pits.

Cat Predation

Domestic and feral cats might also be considered an anthropogenic source of bird mortality. 1990 U.S. census data report 60 million cats claimed as pets by owners, and an unknown number of unclaimed feral cats. Coleman and Temple (1996) estimated that between 8-219 million birds are killed by free-ranging cats in Wisconsin alone. These figures are derived from estimates that there are 1.4 - 2 million free-ranging cats in rural Wisconsin, that each cat on average kills between 28 and 365 animals per year, and that on average 20 to 30 percent of the animals killed by cats are birds (5 -100 birds/cat/year). We use the estimate of 100 million birds killed by cats on an annual basis, but this estimate is likely conservative. If the Wisconsin estimates are representative of the averages nationwide, this estimate is highly conservative given that there are 50 states and because it only accounts for cats claimed as pets by owners.

Electrocutions

Recent prosecution of the Moon Lake Utility for violations of the Bald and Golden Eagle Act and the Migratory Bird Treaty Act (Manville this volume a) has brought more attention to the continued problem of electrocutions of raptors from powerlines. It appears that nation wide mortality estimates from electrocutions are not available. Most data available were not collected in a systematic fashion, and do not attempt to adjust for scavenging and searcher efficiency biases.

In a review of mortality reports from utilities, wildlife rehabilitators and falconers between 1986 and 1996, 1450 raptor electrocutions representing 16 species were confirmed, with Golden Eagles accounting for the largest percentage of fatalities (Harness and Wilson 2001).

Fishing By-catch

Many groups of seabirds have been reported drowned by fishing nets and gear (Atkins and Heneman 1987) and yearly mortality may reach hundreds of thousands (Manville this volume b). Quality studies on the impacts from commercial fishing are absent except for a few studies (e.g., Brothers 1991), and most mortality reports are largely anecdotal.

Cumulative Mortality

Based on the estimates derived or reviewed in this paper, annual bird mortality from anthropogenic sources may easily approach 1 billion birds a year in the US alone (*table 2*). Buildings, power lines and cats are estimated to comprise approximately 82 percent of the mortality, vehicles 8 percent, pesticides 7 percent, communication towers 0.5 percent, and wind turbines 0.003 percent. Other sources such as mortality from electrocution, oil spills and fishing by-catch are also contributors but estimates were not made and we have not even considered the impacts from loss of habitat which could also be considered anthropogenic.

Discussion

Based on existing projections and projections made in this paper, annual avian mortality from anthropogenic causes may be near 1 billion. Given the uncertainty in the estimates, the true avian mortality, especially for communication towers, buildings and windows, vehicles, powerlines, pesticides, oil spills, fishing by-catch, cats, and vehicles could easily be different by an order of magnitude. In general, these sources of mortality continue to grow as our population grows (e.g., buildings and houses), and demand for efficient communications (e.g., cellular telephones), electricity (e.g., wind turbines and powerlines), fuel and other comforts of life grow as well. Although there is high variability in the estimated magnitude of total bird mortality for the different sources, there is also high variability in the types of birds (nocturnal migrants versus residents) and species that individual sources impact. Therefore, the significance on any one source or a particular location of a unit (e.g., a communication tower) may vary greatly depending on the species or groups of birds that may be impacted.

Many of the collision mortality studies have been conducted in response to a known or perceived risk, and therefore are probably not appropriate for extrapolation in the same manner we extrapolated for wind turbines. However, it has been argued by several researchers making mortality projections that their estimates are probably conservative (underestimates), given that scavenging and searcher efficiency biases have generally not been incorporated into the estimates. For example, Banks' (1979) estimate of vehicle mortality was based on the Hodson and Snow (1965) estimate of 15.1 birds per mile (9.4 bird/km), which was based on weekly surveys that did not adjust for scavenging and searcher efficiency.

The large uncertainties associated with estimates of mortality from one or multiple sources, along with the even larger uncertainties in bird populations (e.g., size, reproduction), makes it extremely difficult to understand the biological significance of human-caused mortality on birds at a population, regional, or even local level (Manville this volume a). Aldrich et al. (1975) estimated there are approximately 10 billion breeding landbirds in the US (excluding Alaska and Hawaii) in the spring, and approximately 20 billion breeding landbirds in the autumn, based on 1973 Breeding Bird Survey data. Based on these estimates and our mortality estimates, approximately 5-10 percent of the populations of breeding landbirds are killed each year from human caused factors. Impacts on individual species may be higher or lower depending on their population levels. The recently published Birds of Conservation Concern (BCC) by the USFWS lists 131 species that may currently have declining population numbers from numerous factors including loss of habitat and human-caused mortality. These are in addition to the 92 species currently listed as Federally threatened or endangered. Very few studies have attempted to determine the significance of human-caused mortality at a population level of an individual species. Based on an intensive radio-telemetry study of a population of Golden Eagles at the Altamont Pass wind plant, it was determined the wind plant was currently not causing a population level decline, but the long-term impact was unknown (Hunt 2002). This study of a relatively small and definable population of eagles was expensive, relatively short-term, and not conclusive.

Rosenberg and Blancher (this volume) discuss a method using Breeding Bird Survey data for better understanding the population status and the impact of human-caused mortality of individual breeding birds. Their approach uses breeding bird survey data, but given the limited and highly variable data on population sizes, survival and reproduction, there are likely huge uncertainties. Until we start to better understand mortality rates and parameters of bird populations, we will not truly understand the biological significance of the mortality. Research and monitoring efforts need to continue and expand so that we can better understand the levels and significance of these mortality sources and we can find better and more effective means for reduction and mitigation of human-caused bird mortality.

There does appear to be a greater awareness of the level of human-caused bird mortality, and there are measures being undertaken to reduce mortality from most, if not all these sources. Programs to reduce night lighting at tall buildings and encourage use of tinted windows appear to be an effective measure to reduce mortality. Marking powerlines with bird flight diverters appears to be an effective and relatively inexpensive way of reducing collision mortality along power lines (Morkill and Anderson 1991, Brown and Drewien 1995). Effective wind project siting, use of underground power lines, unguyed meteorological towers, and reduced lighting within wind projects appears to be an effective way of reducing the collision potential at wind projects (Johnson et al. in press). Programs like Audubon's "Keep Cats Indoors" likely reduce bird mortality from free-ranging cats. The U.S. ban on some granular pesticides know to be highly toxic to birds has presumably reduced cumulative mortality from pesticides. Use of unguyed cell towers and better lighting on communication towers may also be contributing to reduced avian mortality. Guidelines for pole configurations to reduce electrocution mortality (APLIC 1996) have undoubtedly help reduce the electrocution risk from power lines. The use of these measures needs to be expanded and other more effective measures need to

Table 2—*Summary of predicted annual avian mortality.*

Mortality source	Annual mortality estimate	Percent composition
Buildings[1]	550 million	58.2 percent
Power lines[2]	130 million	13.7 percent
Cats[3]	100 million	10.6 percent
Automobiles[4]	80 million	8.5 percent
Pesticides[5]	67 million	7.1 percent
Communications towers[6]	4.5 million	0.5 percent
Wind turbines[7]	28.5 thousand	<0.01 percent
Airplanes	25 thousand	<0.01 percent
Other sources (oil spills, oil seeps, fishing by-catch, etc.)	not calculated	not calculated

[1] Mid-range of fatality estimates reported from Klem (1990), 1 – 10 bird fatalities per house, extrapolated to 100 million residences
[2] Based primarily on a study in the Netherlands (Koops 1987), extrapolated to 500,000 miles of bulk transmission line in U.S.
[3] One study in Wisconsin estimated 40 million (Coleman and Temple 1996), there are 60 million cats claimed as pets in the U.S.
[4] Based primarily on one study in England (Hudson 1965, Banks 1979) that estimated 15.1 fatalities/mile of road each year, no searcher efficiency or bias adjustments in that study, updated based on increase in vehicle registrations
[5] Conservative estimate using low range of empirical fatality rate (0.1 to 3.6 birds/acre), studies typically adjusted from searcher efficiency and scavenging
[6] Estimates from models derived by Manville and Evans (M. Manville, pers. comm.).
[7] Mid-range of per turbine and per MW estimates derived from empirical data collected at several wind projects (*table 1*).

be developed to help compensate for the continued growth of human development on the landscape resulting in loss of bird habitat.

Acknowledgments

The effort to gather and summarize much of the literature in this document was funded by DOE, with direction and support from the Wildlife Working Group of the National Wind Coordinating Committee. Most of the collision mortality information was first reported in the NWCC Resource Document entitled "Avian collisions with wind turbines: A summary of existing studies and comparisons to other sources of avian collision mortality in the United States" (Erickson et al. 2001). We appreciate the comments from the reviewers of that report, including K. Sinclair (National Renewable Energy Laboratory), A. Manville (USFWS), P. Kerlinger (Curry and Kerlinger), S. Ugoretz (Wisconsin Department of Natural Resources), T. Gray (American Wind Energy Association), and J. Stewart (FPL Energy). We also appreciate the comments on this manuscript from C. J. Ralph.

Literature Cited

Aldrich, J. W., R. C. Banks, T. J. Cade, W. A. Calder, F. G. Cooch, S. T. Emlen, G. A. Greenwell, T. R. Howell, J. P. Hubbard, D. W. Johnston, R. F. Johnston, and L. R. Mewaldt. 1975. **Report of the American Ornithologist; Union and ad hoc Committee on Scientific and Educational Use of Birds.** Auk 92 (3, Supple.): 1A-27A.

Anderson, R. L., M. Morrison, K. Sinclair and D. Strickland. 1999. **Studying wind energy/bird interactions: A guidance document**. National Wind Coordinating Committee /RESOLVE, Washington, D.C.; 87p.

Ashley, E. P. and J. T. Robinson. 1996. **Road mortality of amphibians, reptiles and other wildlife on the Long Point Causeway, Lake Erie, Ontario**. Canadian Field-Naturalist 110: 403-412.

Atkins, N. and B. Heneman. 1987. **The dangers of gill netting to seabirds**. American Birds 41(5): 1395-1403.

Avian Power Line Interaction Committee (APLIC). 1996. **Suggested practices for raptor protection on power lines: the state of the art in 1996.**

Bagg, A. M. 1971. **The Changing Seasons**. American Birds 25(1): 16-23.

Balcomb, R. 1986. **Songbird carcasses disappear rapidly from agricultural fields**. Auk 103: 817-820.

Banks, R. C. 1979. **Human related mortality of birds in the United States**. Special Scientific Report, Wildlife No. 215. Washington, DC: Fish and Wildlife Service, U. S. Department of the Interior.; 16p.

Bierly, M. L. 1968. **Television tower casualties at Birmingham [Alabama] in 1967**. Alabama Birdlife 16: 34-35.

Bierly, M. L. 1969. **1968 Birmingham [Alabama] tower casualties**. Alabama Birdlife 17: 46-49.

Bierly, M. L. 1972. **Spring 1969 tower casualties in Birmingham**. Alabama Birdlife 20(1-2): 3.

Bird Strike Committee USA. 2000. **Understanding and reducing bird hazards to aircraft.** BSC-USA, 6100 Columbus Avenue. Sandusky, OH 44870.

Bjorge, R. R. 1987. **Birds kill at an oil industry flare stack in northwest Alberta**. The Canadian Field-Naturalist 101: 346-350.

Brothers, N. 1991. **Albatross mortality and associated bait loss in the Japanese longline fishery in the Southern Ocean**. Biological Conservation 55: 255-268.

Brown, W. M. and R. C. Drewien. 1995. **Evaluation of two power line markers to reduce crane and waterfowl collision mortality**. Wildlife Society Bulletin 23(2): 217-227.

Burger, A. E. 1993. **Mortality of seabirds assessed from beach-bird surveys in southern British Columbia.** Canadian Field-Naturalist 107(2): 164-176.

Byrne, S. 1983. **Bird movements and collision mortality at a large horizontal axis wind turbine**. Cal-Neva Wildlife Transactions 1983: 76-83.

Byrne, S. 1985. **Ecological monitoring**. In: MOD-2 wind turbine field experience in Solano County, California. Research Project 1996-3. Pacific Gas & Electric Co., San Ramon, CA; 7-1 to 7-6 and F-1 to F-35.

California Energy Commission (CEC). 1989. **Avian mortality at large wind energy facilities in California: identification of a problem**. California Energy Commission staff report P700-89-001.

Case, L. D., H. Cruickshank, A. E. Ellis, and W. F. White. 1965. **Weather causes heavy bird mortality**. Florida Naturalist 38(1): 29-30.

Case, R. M. 1978. **Interstate highway road-killed animals: a data source for biologists**. Wildlife Society Bulletin 6: 8-13.

Coleman, J. S. and S. A. Temple. 1996. **On the prowl**. Wisconsin Natural Resources; December issue.

Cooley, C. D. 1977. **Television tower casualties at Huntsville [Alabama]: fall, 1976**. Alabama Birdlife 25(3-4): 14-15.

Coues, E. 1876. **The destruction of birds by telegraph wire**. American Naturalist 10(12): 734-736.

Crawford, R. L. 1971. **Predation on birds killed at TV tower**. The Oriole December 1971: 33-35.

Crawford, R. L. and R. T. Engstrom. 2000. **Characteristics of avian mortality at a north Florida television tower: A 28-year experience**. Tallahassee, FL Tall Timbers Research Station.

Decker, D. 1987. **A limited survey of roadkills on the Warsaw-Hamilton blacktop**. Illinois Birds and Birding 3: 63-4.

Di Silvestro, R. 1996. **Poison in the Pampas: What's killing the Swainson's hawk?** International Wildlife 26(3): 38-43.

Dunn, E. H. 1993. **Bird mortality from striking residential windows in winter**. Journal of Field Ornithology 64(3): 302-309.

Dunthorn, A. A. and F. P. Errington. 1964. **Casualties among birds along a selected road in Wiltshire**. Bird Study 11: 168-182.

Edison Electric Institute. 2000. **The living grid: Evolving to meet the power needs of America**. Washington, DC: Energy Issues/News.

Erickson, W. P., M. D. Strickland, G. D. Johnson, and J. W. Kern. 2000a. **Examples of statistical methods to assess risk of impacts to birds from windplants**. In: Proceedings of the National Avian-Wind Power Planning Meeting III. National Wind Coordinating Committee, c/o RESOLVE, Inc., Washington, D.C.

Erickson W. P., G. D. Johnson, M. D. Strickland, and K. Kronner. 2000b. **Avian and bat mortality associated with the Vansycle wind project, Umatilla County, Oregon, 1999 study year**. Pendleton, OR: Technical report prepared for Umatilla County Department of Resource Services and Development.

Erickson, W. P., G. D. Johnson, M. D. Strickland, D. P. Young, Jr., K. J. Sernka, and R. E. Good. 2001. **Avian collisions with wind turbines: A summary of existing studies and comparisons to other sources of avian collision mortality in the United States**. National Wind Coordinating Committee, c/o RESOLVE, Inc., Washington, D.C.

Esmoil, B. J. 1995. **Wildlife mortality associated with oil pits in Wyoming**. Prairie Naturalist 27(2).

Evans, B. 1998. **Telecommunications towers affect avian community**. Wave-Guide Information, Tower-Related Bird Kill Rates. 421 Titus Ave., Ithaca, NY 14850

Faanes, C. A. 1987. **Bird behavior and mortality in relation to powerlines in prairie habitats**. Fish and Wildlife Technical Report, No. 7. Washington, DC: Fish and Wildlife Service, U.S. Department of the Interior.

Federal Communications Commission (FCC). 2002. **Antenna structure registry database quarterly update**. Gettysburg, PA: July 2002; 1 p.

Finnis, R. G. 1960. **Road casualties among birds**. Bird Study 7: 21-32.

Flint, P. A., A. C. Fowler, and R. F. Rockwell. 1999. **Modeling bird mortality associated with the M/V Citrus oil spill off St. Paul Island, Alaska**. Ecological Modeling, 117: 261-267.

Gauthreaux, S. 1994. **The history of wind-related avian research in the U.S.A.** In: Proceedings of the National Avian-Windpower Planning Meeting. Washington, DC: National Wind Coordinating Committee c/o RESOLVE Inc.; 33-35

Harness, R. E. and K. R. Wilson. 2001. **Electric-utility structures associated with raptor electrocutions in rural areas**. Wildlife Society Bulletin 29: 612-623.

Hawrot, R. Y. and J. M. Hanowski. 1997. **Avian assessment document: avian population analysis for wind power generation regions--012**. NRRI Technical Report No. NRRI/TR-97-23. Duluth, MN: Center for Water and the Environment, Natural Resources Research Institute; 14p.

Hodson, N. L. 1962. **Some notes on the causes of bird road casualties**. Bird Study 9: 168-173.

Hodson, N. L. and D. W. Snow. 1965. **The road deaths enquiry, 1960-61**. Bird Study 9: 90-99.

Howell, J. A. 1997. **Bird mortality at rotor swept area equivalents, Altamont Pass and Montezuma Hills, California**. Transactions of the Western Section of The Wildlife Society 33: 24-29.

Hugues, B. 1996. **Barn Owl (*Tyto alba*) and Long-eared Owl (*Asio otus*) mortality along motorways in Bourgogne-Champagne: Report and Suggestions**. 2nd Owl Symposium; 58-61.

Hunt, W. G. 2002. **Golden Eagles in a perilous landscape: Predicting the effects of mitigation for energy-related mortality**. Report to the California Energy Commission, PIER Grant No. 500-97-4033 to the University of California, Santa Cruz, CA.

Johnson, G. D., W. P. Erickson, M. D. Strickland, M. F. Shepherd, D. A. Shepherd, and S. A. Sarappo. 2002. **Collision mortality of local and migrant birds at a large-scale wind power development on Buffalo Ridge, Minnesota**. Wildlife Society Bulletin 30: 879-887.

Johnson, G. D., M. D. Strickland, W. P. Erickson, and D. P. Young, Jr. In press. **Use of data to develop mitigation measures for wind power development impacts to birds**. In: M. Ferrer, G. Janss, and M. de Lucas, editors. Birds and windpower. Spain: Quercus Press.

Johnston, D. W. and T. P. Haines. 1957. **Analysis of mass bird mortality in October, 1954**. The Auk 74: 447-458.

Kemper, C. 1996. **A study of bird mortality at a west central Wisconsin TV tower from 1957-1995**. The Passenger Pigeon 58: 219-235.

Kerlinger, P. 2000. **Avian mortality at communication towers: a review of recent literature, research, and methodology**. Unpublished report prepared for: The U.S. Fish and Wildlife Service, Office of Migratory Bird Management. Curry and Kerlinger, P.O. Box 453, Cape May Point, NJ 08212.

Klem, D., Jr. 1990. **Collisions between birds and windows: mortality and prevention**. Journal of Field Ornithology 61(1): 120-128.

Koops, F. B. J. 1987. **Collision victims of high-tension lines in the Netherlands and effects of marking**. KRMA Report 01282-MOB 86-3048.

Larkin, Ronald P. and Barbara A. Frase. 1988. **Circular paths of birds flying near a broadcasting tower in cloud**. Journal of Comparative Psychology 102: 90-93.

Loos, G. and P. Kerlinger. 1993. **Road mortality of Saw-whet and Screech-owls on the Cape May peninsula**. Journal of Raptor Research 27(4): 210-213.

Maehr, D. S., A. G. Spratt, and D. K. Voigts. 1983. **Bird casualties at a central Florida power plant**. Florida Field Naturalist 11(3): 45-68.

Maehr, D. S. and J. Q. Smith. 1988. **Bird casualties at a central Florida power plant: 1982-1986**. Florida Field Naturalist 16: 57-80.

Manville, A. 2000. **The ABCs of avoiding bird collisions at communication towers: the next steps**. In: Proceedings of the Avian Interactions Workshop, December 2, 1999, Charleston, SC. CA: Electric Power Research Institute; 15p.

Manville, M. This volume a. **Bird strikes and electrocutions at communication towers, power lines and wind turbines: State of the art and state of the science – Next steps toward mitigation**.

Manville, M. This volume b. **Seabird and waterbird bycatch in fishing gear: Next steps in dealing with a problem**

McCrary, M. D., R. L. McKernan, R. E. Landry, W. D. Wagner, and R. W. Schreiber. 1983. **Nocturnal avian migration assessment of the San Gorgonio wind resource study area, spring 1982**. Report prepared for: Research and Development, Southern California Edison Company, Rosemead, California; 121 p.

McCrary, M. D., R. L. McKernan, W. D. Wagner, and R. E. Landry. 1984. **Nocturnal avian migration assessment of the San Gorgonio wind resource study area, fall 1982**. Report prepared for: Research and Development, Southern California Edison Company, report #84-RD-11. Rosemead, California; 87p.

McCrary, M. D., R. L. McKernan, and R. W. Schreiber. 1986. **San Gorgonio wind resource area: Impacts of commercial wind turbine generators on birds, 1985 data report**. Report prepared for: Southern California Edison Company, Rosemead, California; 33p.

McClure, H. L. 1951. **An analysis of animal victims on Nebraska highways**. Journal of Wildlife Management 15(4): 410-420.

Mineau. P. 1988. **Avian mortality in agroecosystems: 1. the case against granule insecticides**. In: M. P Greaves, B. D. Smith, and P. W. Greig-Smith, editors. Field methods for the study of environmental effects of pesticides, proceedings of a symposium organized by the British Crop Protection Council, Churchill College, Cambridge, UK; 13-27.

Mineau, P. This volume. **Direct losses of birds to pesticides – Beginnings of a quantification**.

Morkill, A. E. and S. H. Anderson. 1991. **Effectiveness of marking powerlines to reduce Sandhill Crane collisions.** Wildlife Society Bulletin 19(4): 442-449.

Morrison, M. 2002. **Searcher bias and scavenging rates in bird/wind energy studies**. NREL/SR-500-30876. National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, Colorado 80401-3393.

Nehring, J. 2000. WSMV Tower study summary 1960-1997. http://www.towerkill.com/TNR/Tndata1a.html. Accessed 11/13/00.

Ogden, L. J. E. 1996. **Collision course: The hazards of lighted structures and windows to migrating birds**. Toronto, Ontario: World Wildlife Fund Canada and the Fatal Light Awareness Program; 46 p.

Orloff, S. and A. Flannery. 1992. **Wind turbine effects on avian activity, habitat use, and mortality in Altamont Pass and Solano County Wind Resource Areas, 1989-1991**. Final Report to Alameda, Contra Costa and Solano Counties and

the California Energy Commission by Biosystems Analysis, Inc., Tiburon, CA. CEC Report No. P700-92-001.

Orloff, S. and A. Flannery. 1996. **A continued examination of avian mortality in the Altamont Pass Wind Resource Area**. Final Report to the California Energy Commission by Biosystems Analysis, Inc., Tiburon, CA. CEC Report No. P700-96-001CN.

Osborn, R. G., K. F. Higgins, R. E. Usgaard, C. D. Dieter, and R. G. Neiger. 2000. **Bird mortality associated with wind turbines at the Buffalo Ridge Wind Resource Area, Minnesota**. American Midland Naturalist 143: 41-52.

Overing, R. 1936. **The 1935 fall migration at the Washington Monument**. Wilson Bulletin 48: 222-224.

Pain, D. J. 1991. **Why are lead-poisoned waterfowl rarely seen?: The disappearance of waterfowl carcasses in the Camargue, France**. Wildfowl 42:118-122.

Piatt, J. F., C. J. Lensink, W. Butler, M. Kendziorek, and D. R. Nysewander. 1990. **Immediate impact of the Exxon Valdez oil spill on marine birds**. The Auk 107: 387-397.

Pimentel, D., A. Greiner, and T. Bashore. 1991. **Economic and environmental costs of pesticide use**. Archives of Environmental Contaminants and Toxicology 21: 84-90.

Remy, R. J., Jr. 1974. **Birmingham tower casualties – fall 1974**. Alabama Birdlife: Journal of the Alabama Ornithological Society 22(3-4): 9-10.

Remy, R. J., Jr. 1975. **Birmingham [Alabama] television tower casualties 1975**. Alabama Bird Life 23(3-4): 18-19.

Rosenberg, K. V. and P. J. Blancher. This volume. **Setting numerical population objectives for priority landbird species**.

Sargeant, A. B. 1981. **Road casualties of prairie nesting ducks**. Wildlife Society Bulletin 9: 65-69.

Sargeant, A. B. and J. E. Forbes. 1973. **Mortality among birds, mammals and certain snakes on 17 miles of Minnesota roads**. Loon 45: 4-7.

Spencer, K. G. 1965. **Avian casualties on railways**. Bird Study 12: 257.

Statistical Abstract of the United States. 1999. **U.S. Census Bureau**.

Stout, I. J. 1967. **The nature of nonhunting mortality in fledged North American waterfowl**. Virginia Polytechnic Institute, Blacksburg, Virginia; Master's thesis.

Taylor, W. K. and M. A. Kershner. 1986. **Migrant birds killed at the Vehicle Assembly Building (VAB), John F. Kennedy Space Center**. Journal of Field Ornithology 57: 142-154.

U. S. Bureau of Reclamation. 1984. **Status report on system verification units: wind-hydroelectric energy project, Wyoming**. Bureau of Reclamation, Wyoming.

Weaver, D. K. and R. St. Ores. 1974. **Trumpeter Swan mortality**. In: Proceedings and Papers of the Third Trumpeter Swan Society Conference, volume 3; 1973 September 18-20; Martin, South Dakota; 86-89.

Weir, R. D. 1976. **Annotated bibliography of bird kills at manmade obstacles: a review of the state of the art and solutions**. Canadian Wildlife Services, Ontario Region, Ottawa.

Willey, C. H. 1968. **The ecology, distribution, and abundance of the Mute Swan (*Cygnus olor*) in Rhode Island**. University of Rhode Island; Master's thesis.

Wobeser, G. and A. G. Wobeser. 1992. **Carcass disappearance and estimation of mortality in a simulated die-off of small birds**. Journal of Wildlife Diseases 28: 548-554.

Young, D. P. Jr., W. P. Erickson, R. E. Good, M. D. Strickland, and G. D. Johnson. 2003. **Avian and bat mortality associated with the initial phase of the Foote Creek Rim Windpower Project, Carbon County, Wyoming: November 1998 - June 2003**. Technical Report prepared by WEST, Inc. (2003 Central Ave, Cheyenne, Wyoming, 82001) for Pacificorp, Inc., SeaWest Wind Power, Inc. and Bureau of Land Management; 35 p.

BIRD POPULATIONS

A journal of global avian biogeography

Volume 10 2010 (2009-2010)

Bird Populations 10:1-36

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ASSESSING CHANGES IN THE DISTRIBUTION AND ABUNDANCE OF BURROWING OWLS IN CALIFORNIA, 1993-2007[1]

ROBERT L. WILKERSON AND RODNEY B. SIEGEL[2]

The Institute for Bird Populations
P.O. Box 1346
Point Reyes Station, CA 94956-1346

Abstract. The Western Burrowing Owl (*Athene cunicularia hypugaea*) has declined in recent decades across much of its range, including California, where it is classified as a Species of Special Concern. During 2006-2007, we surveyed the entire breeding range of the species in California, except the Channel Islands. Relying largely on volunteers, we surveyed 860 5km x 5km blocks, and documented exact locations of 1,758 pairs. Using data from randomly-selected blocks, we extrapolated a statewide, breeding-season population of 9,187 (SE = 2,346) pairs. For all of the species' California range, except the Modoc Plateau and the Mojave and Sonoran deserts, we compared results with those of DeSante et al. (2007) using identical methods and study area boundaries during 1991-1993. Our 2006-2007 estimate of 8,128 (SE = 2,391) pairs was 10.9% lower than the previous estimate, but the difference was not statistically significant. The major patterns of Burrowing Owl occurrence across California appeared to be relatively unchanged since 1993, although non-significant declines were apparent in numerous regions. Burrowing Owls appear to have declined particularly sharply in two urban areas: the San Francisco Bay Area and Bakersfield. Our surveys of previously unsurveyed portions of the species' California range yielded few or no owls in the Modoc Plateau/Great Basin, Northern Mojave/eastern Sierra Nevada, eastern Mojave, and Sonoran Desert regions (excluding the Palo Verde Valley) but detected large aggregations in the Palo Verde Valley and the western Mojave Desert region.

Key words: Burrowing Owl, California, Athene cunicularia, *citizen science*

EVALUAR LOS CAMBIOS EN LA DISTRIBUCIÓN Y ABUNDANCIA DEL BÚHO LLANERO EN CALIFORNIA, 1993-2007

Resumen. El Búho Llanero (*Athene cunicularia hypugaea*) ha disminuido en las últimas décadas en gran parte de su distribución, incluyendo a California, donde está clasificado como una especie de interés especial. Durante el periodo 2006-2007, encuestamos a todo el rango reproductivo de la especie en California, con la excepción de las Channel Islands.

[1]Submitted: 20 April 2010; accepted 11 June 2010

[2]Corresponding author: rsiegel@birdpop.org

Dependimos en gran medida de voluntarios para contar búhos en 860 bloques de 5 km x 5 km, y para documentar la ubicación exacta de 1,758 parejas. Usando datos de los bloques seleccionados al azar, extrapolamos una población para la temporada de reproducción en todo el estado de 9,187 (SE = 2,346) pares. En toda la distribución de la especie de California, con excepción de la Modoc Plateau y los Mojave y Sonoran Deserts, se compararon los resultados con los de DeSante et al. (2007) utilizando métodos idénticos y los límites del área de estudio durante 1991-1993. Nuestra 2006-2007 estimación de 8,128 (SE = 2,391) pares fue 10.9% inferior a la estimación anterior, pero la diferencia no fue estadísticamente significativa. Los principales patrones de ocurrencia del Búho Llanero a través de California parece no haberse cambiado desde 1993. Aunque hubo disminuciones evidentes en numerosas regiones, éstas no fueron estadisticamente significativas. La disminución del Búho Llanero fue especialmente marcada en dos áreas urbanas: el San Francisco Bay Area y Bakersfield. Nuestro estudio de las regiones préviamente no investigadas de distribución de la especie de California dio pocos o ningunos búhos en la Modoc Plateau/Great Basin, el norte de Mojave/este de Sierra Nevada, el este de Mojave, y regiones del Sonoran Desert (excluyendo el Palo Verde Valley), pero detectó grande agregaciones en el Palo Verde Valley y la región occidental del Mojave Desert.

Palabras clave: Búho Llanero, California, *Athene cunicularia*, ciencia ciudadana

INTRODUCTION

Burrowing Owls (*Athene cunicularia hypugaea*) in California breed in natural grasslands and a variety of human-modified habitats, including areas of intense agriculture (Cuolombe 1971, DeSante et al. 2004), as well as airports (Thomsen 1971, Barclay 2007b) and other open areas in urban environments (Trulio 1997, Trulio and Chromczak 2007). Once considered "abundant" and "common" throughout California (Baird 1870, Keeler 1891, Grinnell 1915, Dawson 1923), the species has been declining since at least the 1940s (Grinnell and Miller 1944, Remsen 1978, James and Ethier 1989, DeSante et al. 2007) and is now classified as a Species of Special Concern (Gervais et al. 2008, Shuford and Gardali 2008). The species has declined throughout much of its range (Wedgwood 1978, James and Ethier 1989, Sheffield 1997a, Holroyd et al. 2001, Wellicome and Holroyd 2001) with suggested causes including conversion of grassland habitats to urbanization and inhospitable forms of agriculture (DeSante et al. 2007, Gervais et al. 2008), eradication of fossorial mammals (Zarn 1974, Remsen 1978, Holroyd et al. 2001) and perhaps exposure to pesticides and other contaminants (James and Fox 1987, Haug et al. 1993, Sheffield 1997b; but see also Gervais and Anthony 2003).

In the early 1990s, DeSante et al. (2007) coordinated a survey of the species' entire California breeding range, except for the Modoc Plateau/Great Basin region and the Mojave and Sonoran deserts. At that time Burrowing Owl populations in the southern San Francisco Bay region and in the northern and central portions of the Central Valley appeared to have been declining rapidly, and populations elsewhere in the census area, including the coastal slope of central and southern California, had virtually disappeared. DeSante et al. (2007) estimated that the entire survey area contained >9,000 pairs, with 71% of the estimated population occupying the Imperial Valley south of the Salton Sea (an area comprising just 2.5% of the state) and 24% occupying the Central Valley, primarily in the southern portion of the San Joaquin Valley. Prior to the present study, adequate information to assess Burrowing Owl population trends since 1993 was not available, and in the Great Basin and Mojave and Sonoran desert regions no systematic assessment of population size had ever been made.

Local-scale demographic studies of four focal populations (Imperial Valley, Carrizo Plain, Naval Air Station Lemoore, and the San Jose area) suggest highly variable demographic rates (Gervais 2002, Ronan 2002, Gervais and Anthony 2003, Rosenberg and Haley 2004). Breeding Bird Survey (Sauer et al. 2008) trend results for California exist but are difficult to interpret, because the great majority of detections are clustered on a small number of

routes in the Imperial Valley, home to one of the largest concentrations of the species anywhere (DeSante et al. 2007).

We undertook the present study to assess how Burrowing Owl distribution and abundance in California may have changed since 1993, and to determine the status of Burrowing Owl populations in the previously unsurveyed Modoc Plateau and desert regions of the state.

METHODS

STUDY AREA

For their 1991-1993 study, DeSante et al. (2007) defined and surveyed 11 distinct geographic regions, comprising the entire California breeding range, except for the Sonoran and Mojave deserts and the Modoc Plateau. To maximize comparability, we retained all of the region boundaries established by DeSante et al. (2007; Fig. 1).

We re-surveyed 8 of the 11 regions defined for the early 1990s survey (Table 1); because populations in the San Francisco Bay Area Coast, Central-western Coast, and Southwestern Coast regions were well studied and known to be very small or extirpated entirely, we opted not to devote volunteer resources to surveying those, but instead to rely on published literature and/or local experts for population estimates.

In addition to resurveying most of the DeSante et al. (2007) regions, we also targeted the state's Modoc/Great Basin and desert, in order to assess the species' heretofore largely unknown abundance and distribution within these areas, and to better understand their relative importance to the state's overall Burrowing Owl population. DeSante et al. (2007) omitted these areas from the 1991-1993 survey because adequate numbers of local volunteer surveyors were not available. We were able to include these regions in the 2006-2007 effort by surveying them with a crew of full-time field technicians, rather than relying on local volunteers.

We divided the previously unsurveyed portions of the California breeding range into five new regions, four of which are described in greater detail in Wilkerson and Siegel (*in press*; Fig. 1): Northern Mojave Desert/Eastern Sierra Nevada, Western Mojave Desert, Eastern Mojave Desert, Sonoran Desert. The fifth, the Modoc Plateau/Great Basin region (Fig. 1), matches the geographic boundaries of the "Jepson area" mapped as "Modoc Plateau" by Hickman (1993) and the California Gap Analysis Project (1998). The region lies entirely above the 610m elevation contour, which was used as the upper limit for high elevation subregions in ten of the 12 regions defined by DeSante et al. (2007). We therefore did not stratify our sampling within this region by elevation. Rather, we classified the entire region as "upland". Because of the presence of large tracts of forested areas that are not suitable Burrowing Owl habitat, we used the Forest Multi-source Landcover Data (California Department of Forestry and Fire Protection 2002) in conjunction with Burrowing Owl habitat characterizations produced for the region by Cull and Hall (2007) to assess the extent of potential habitat within each survey block. All land area above 1,830m was excluded from the sample frame because it consists of mountainous and forested habitat. We classified the remaining survey blocks as having either greater than or less than 50% suitable Burrowing Owl habitat, and then drew our random sample of blocks such that 2/3 had >50% suitable habitat cover and 1/3 had <50% suitable habitat cover. Survey blocks with <5% suitable habitat cover were not included.

SURVEY DESIGN

Within each region previously surveyed by DeSante et al. (2007), we used the grid defined for their 1991-1993 survey, which divides all the land in the study area into 5-km by 5-km blocks, oriented and referenced according to the Universal Transverse Mercator (UTM) system. Each block was classified as belonging primarily to the lowland subregion or the upland subregion, using a set of classification rules that varied slightly by region (see details in DeSante et al. 2007). Survey effort was stratified by elevational subregion because Burrowing Owl densities are generally much higher in lowland areas throughout California than in upland areas (DeSante et al. 2007). For logistical reasons, we discarded the small number of blocks that could not be accessed anywhere by roads, and then stratified sampling effort among the remaining blocks by region and subregion, randomly selecting as many blocks as we

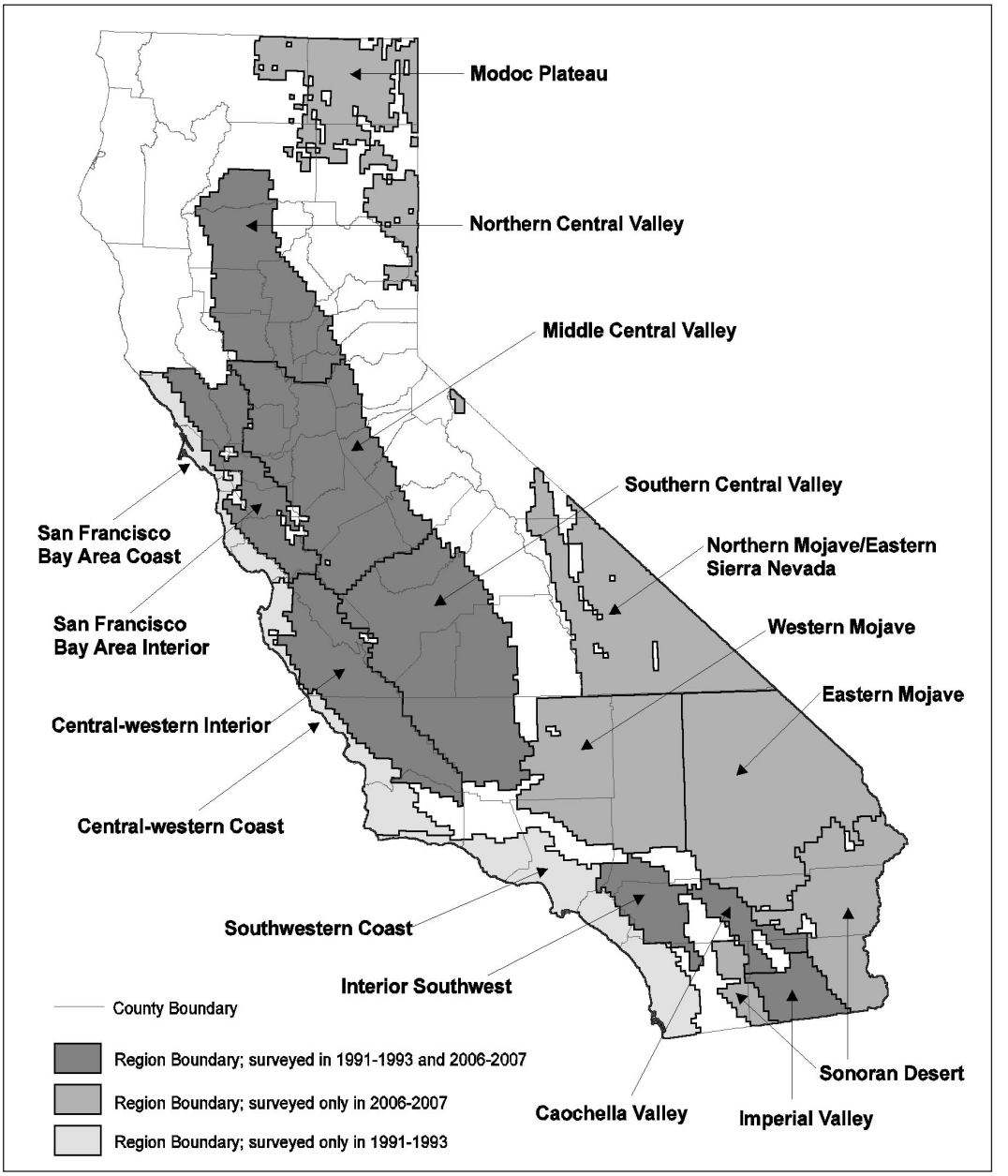

FIGURE 1. Burrowing Owl regions delineated and surveyed for The Institute for Bird Populations' 1991-1993 and/or 2006-2007 statewide Burrowing Owl surveys.

thought we would have the manpower to survey. Blocks in each region were then assigned to be surveyed in a randomly determined order to avoid bias if our volunteers and field crew were unable to survey all of the selected blocks.

We used Geographic Information System (GIS) software to define grids of 5-km by 5-km blocks covering each of the four new regions in a manner consistent with the previously established grid. The 1991-1993 survey drew from a sampling frame of 5,990 blocks (DeSante et al. 2007). The five new survey regions

TABLE 1. Regions of California defined and surveyed for The Institute for Bird Populations' California Burrowing Owl surveys during 1991-1993 and/or 2006-2007.

Region	Status during 2006-2007 survey
Regions surveyed during the 1991-1993 survey	
Northern Central Valley	Resurveyed
Middle Central Valley	Resurveyed
Southern Central Valley	Resurveyed
San Francisco Bay Area Interior	Resurveyed
San Francisco Bay Area Coast	Not resurveyed – population extirpated
Central-western Interior	Resurveyed
Central-western Coast	Not resurveyed – population likely extirpated
Southwestern Coast	Not resurveyed – small, well-known population
Southwestern Interior	Resurveyed
Coachella Valley	Resurveyed
Imperial Valley	Resurveyed
Regions not previously surveyed	
Modoc Plateau/Great Basin	Surveyed for the first time
Northern Mojave Desert/Eastern Sierra Nevada	Surveyed for the first time
Western Mojave Desert	Surveyed for the first time
Eastern Mojave Desert	Surveyed for the first time
Sonoran Desert	Surveyed for the first time

contained an additional 4,991 blocks. After removing those regions from the 1991-1993 survey we decided not to survey, our sampling frame contained a total of 9,823 blocks.

Random sample blocks were selected separately by region and elevation stratum. The selected number of blocks to be visited in each subregion was proportional to its size and amount of estimated surveyor effort available over the two-year survey period. Because Burrowing Owls are known to be more abundant in the lower elevation strata throughout our sample area (DeSante et al. 2007), low elevation blocks comprised 2/3 of the random sample selected to be visited while high elevation substrata blocks comprised 1/3 of selected random sample blocks in all survey regions.

We also identified additional blocks (hereafter, "historic breeding blocks") where Burrowing Owls were known to have been detected during the breeding season in any year since 1981. Historic breeding blocks were identified by querying or consulting the following sources for historical detections: the database compiled by DeSante et al. (2007), which includes Burrowing Owls detected during the 1991-1993 survey as well as historical detections gathered from multiple sources from the decade prior to that survey; the California Natural Diversity Database (CNDDB; California Dept. Fish and Game 2006); and knowledgeable researchers and birders with local expertise throughout the state.

Based on previous knowledge from the 1991-1993 survey, we estimated that it was feasible to visit approximately 670 blocks in the eight regions being resurveyed, and 230 blocks in the five new survey regions, for a total of 900 blocks. Prior to the 2006 field season, we identified 500 historic breeding blocks (459 historic breeding blocks in the eight regions surveyed in 1991-1993 and 41 historic breeding blocks in the five new survey regions); a few additional historic blocks were identified during the course of our two-year survey. We also selected 520 random blocks to be surveyed: 340 in regions scheduled to be resurveyed and 180 in the new regions, of which 47 also happened to be historic breeding blocks in which Burrowing Owls had been detected during the 1991-1993 survey. The total number of blocks drawn for surveying during 2006-2007 was 973 (slightly more than we thought we could survey, in case some selected blocks proved to be inaccessible or we were able to sample more blocks than we anticipated).

All selected blocks were assigned to a randomly generated order. In each subregion, half of all blocks in each elevation stratum and each category (random or historic) were

TABLE 2. Number of blocks surveyed, Burrowing Owl pairs found, and population estimate for each geographic region surveyed during 2006-2007 that was also surveyed in 1991-1993 by DeSante et al. (2007). For each region and elevational subregion, we considered our "best estimate" of the number of pairs in 2006-2007 to be the larger of a) the extrapolated estimate of pairs, based only on results from randomly-selected blocks, or b) the actual number of pairs counted, pooling data from randomly-selected blocks and historic breeding blocks.

		All blocks			Random blocks only				
Region	Total area of region (km2)	Random & historic breeding blocks surveyed	Square km surveyed	No of pairs found	Random blocks surveyed	Square km surveyed	No. of pairs found	Estimated no. of pairs (SE)	"Best estimate"of no. of pairs (SE)[a]
Northern Central Valley									
Lowland	10,900	37	822	12	22	497	0	0	12
Upland	8,975	11	252	0	11	252	0	0	0
All	19,875	48	1,074	12	33	749	0	0	12
Middle Central Valley									
Lowland	16,400	174	3,903	339	59	1,265	34	502 (209)	502 (209)
Upland	10,858	25	433	43	12	236	0	0	43
All	27,258	199	4,336	382	71	1,501	34	502 (209)	545 (209)
Southern Central Valley									
Lowland	18,650	121	2,902	204	63	1,544	72	968 (342)	968 (342)
Upland	13,025	43	714	32	18	323	3	145 (118)	145 (118)
All	31,675	164	3,616	236	81	1,867	75	1,113 (460)	1,113 (460)
San Francisco Bay Area Interior									
Lowland	4,903	69	1,592	98	20	447	0	0	98
Upland	6,275	21	515	14	12	290	1	21 (21)	21 (21)
All	11,178	90	2,107	112	32	737	1	21 (21)	119
Central-western Interior									
Lowland	5,325	20	308	8	17	276	0	0	8
Upland	11,225	24	477	13	13	233	2	76 (51)	76 (51)
All	16,550	44	785	21	30	509	2	76 (51)	84
Southwestern Interior									
Lowland	1,250	12	301	37	3	75	1	17 (17)	37
Upland	5,050	56	1,265	113	8	173	0	0	113
All	6,300	68	1,566	150	11	248	1	17 (17)	150
Coachella Valley									
Lowland	1,615	10	245	12	4	100	1	16 (16)	16 (16)
Upland	2,350	10	251	37	4	100	0	0	37
All	3,965	20	496	49	8	200	1	16 (16)	53

TABLE 2. Continued.

Region	Total area of region (km2)	All blocks			Random blocks only				
		Random & historic breeding blocks surveyed	Square km surveyed	No of pairs found	Random blocks surveyed	Square km surveyed	No. of pairs found	Estimated no. of pairs (SE)	"Best estimate" of no. of pairs (SE)[a]
Imperial Valley									
Lowland	2,810	12	301	499	5	126	254	5,701 (2,244)	5,701 (2,244)
Upland	1,780	3	53	22	2	50	17	707 (140)	707 (140)
All	4,590	15	354	521	7	176	271	6,408 (2,384)	6,408 (2,384)

[a] For each subregion we considered our "best estimate" of the number of Burrowing Owl pairs to be the larger of a) the extrapolated estimate of pairs, based only on results from randomly-selected blocks, or b) the actual number of pairs counted, pooling data from randomly-selected blocks and historic breeding blocks. We then summed the "best estimate" for each subregion to obtain "best estimates" for each region.

assigned to observers for sampling in year one (2006) based on the firing order. All random and historic blocks not sampled in 2006 were assigned to be surveyed in 2007. Most blocks were sampled during one of the two years in our survey period. In the few instances that a block was surveyed during both years (generally because volunteer observers became interested in "their" blocks during 2006 and independently chose to resurvey them in 2007), we used data from the first survey year (2006) in our analysis.

DATA COLLECTION

Adhering to the strategy developed by DeSante et al. (2007), we relied largely upon volunteer observers, many associated with local California Audubon Society chapters, to collect our field data in the regions that were surveyed during 1991-1993. We also deployed a crew of full-time field biologist technicians to a) survey some of the blocks in regions where the number of volunteer observers was inadequate to reasonably survey all the selected blocks, and b) survey all of the selected blocks in the Sonoran, Mojave, and Great Basin regions, where potential volunteers were very scarce.

Volunteer surveyors and IBP field crews surveyed blocks using the field methodology developed for the 1991-1993 survey (DeSante et al. 2007). For most regions, surveyors were instructed to visually scan all of the area in their blocks at least once during morning (dawn to 10:00 AM) or late-afternoon (4:00 PM to dusk) during the two-month period between May 15 and July 15, when breeding Burrowing Owls are likely to be feeding nestlings or recently-fledged young. The survey season was shifted two weeks earlier in the Western and Eastern Mojave Desert, Sonoran Desert, Southwestern Interior, and the Coachella and Imperial Valley regions to account for phenological differences among areas.

We provided surveyors with 1:24,000 scale topographic maps with survey block boundaries and clearly marked locations of any owls known or suspected to have bred anytime since 1981. Surveyors delineated the extent of appropriate habitat in their block, visually scanned all areas of appropriate habitat for owls, and plotted the locations of any detections on their maps. For each detection location, observers provided a

count of all owls seen (identified to age and sex, if possible), an estimate of the number of breeding pairs present, and standardized habitat information. The latter included information on vegetation community type and structure, land use, distance to irrigation canals, local abundance of ground squirrels, and other variables. Finally, observers provided a detailed assessment of how much of their block they were actually able to survey adequately. In some cases this was <100%, due to private property restrictions or physiographic barriers.

For each region (except for the Modoc Plateau and desert regions where we relied strictly on IBP field crews) we recruited one or more local area coordinators, who helped recruit volunteers and coordinate their efforts. Prior to the start of the first field season, we developed a training presentation to explain the rationale and goals of the survey, provide tips for identifying Burrowing Owls and determining their age and sex, and teach volunteers how to conduct the survey and complete data forms in a standardized manner. We gave the presentation at eight live meetings and workshops, and also posted it as an online presentation on our website so that it was available to volunteers who could not attend a local training session. We also prepared a detailed data collection protocol which was provided to all observers prior to data collection.

STATISTICAL ANALYSES

We estimated the number of breeding pairs in each subregion and region surveyed. First we calculated the density of breeding pairs on each randomly-selected surveyed block, as the quotient of the number of pairs observed divided by the area of the block that was adequately surveyed. Densities were then averaged across all randomly-selected blocks surveyed in each subregion. Estimates are presented with standard errors, except in cases where the estimate was zero pairs and the SE could not be calculated.

For each subregion and region, we also totaled the actual number of pairs detected, as the sum of all pairs found on randomly-selected blocks plus all pairs found on historic breeding blocks. We present these totals without standard errors, since they are minimum counts rather than statistical estimates.

For each subregion, we considered our "best estimate" of the number of Burrowing Owl pairs to be the larger of a) the extrapolated estimate of pairs, based only on results from randomly-selected blocks, or b) the minimum number of pairs counted, pooling data from randomly-selected blocks and historic breeding blocks (in other words, we only used the minimum count as our "best estimate" if it was larger than the extrapolated estimate). We then summed the "best estimate" for each subregion to obtain "best estimates" of the number of pairs in each region, and across the state.

For subregions and regions surveyed in the 1990s, we compared the 2006-2007 population estimate (no. of pairs) with the estimate obtained for 1991-1993 by a) using Levene's Test to determine whether variances for the two estimates were similar, and then b) using F-tests to assess statistical significance of differences between the estimates (Zar 1984). Such comparisons were only possible when our best estimate for the number of pairs in a region was derived from randomly-selected sample blocks; in cases where our "best estimate" was the actual number of pairs counted (aggregating results from randomly-selected blocks and historic breeding blocks) there was no variance associated with the estimate, so we provide only qualitative, rather than statistical, assessments of population change since the early 1990s.

We used ArcMap to determine land ownership (public versus private) or land managing agency (various federal agencies, state government, local government, tribal areas) at all occupied sites, based on the California Department of Fish and Game Region 6 Spatial Data Framework's Public and Conservation Lands shapefile ("govconfee_1").

We used a paired t-test to assess whether owl abundance changed between the 1991-1993 and 2006-2007 surveys for historic breeding blocks where owls were detected during 1991-1993. We used logistic regression to assess whether the probability of detecting owls on these blocks during 2006-2007 was related to the number of owl pairs detected on them during 1991-1993.

RESULTS

With the help of 21 local coordinators, we recruited 394 volunteers to participate in

surveying one or more blocks during the 2006 or 2007 field season. These volunteers spent over 6,400 hr surveying blocks and completing data forms. Their efforts were augmented by our full-time crews of field biologist technicians, who largely focused their efforts in the new survey regions, where few volunteers were available, and in the southern Central Valley, where the large number of historic breeding blocks surpassed the survey capacity of the local pool of volunteers.

During our 2006-2007 efforts we were able to complete surveys at 453 of the 500 historic breeding owl blocks identified prior to the start of the 2006 field season; 47 historic breeding blocks thus went unsurveyed. However, 24 of those unsurveyed historic breeding blocks were surveyed but yielded no owl detections during the 1991-1993 survey. In other words, the occupancy records were from before 1991-1993, and occupancy could not be confirmed during the 1991-1993 survey. Thus, only 26 historic blocks known to have owls during the 1991-1993 survey went unsurveyed during 2006-2007.

We completed surveys of 860 blocks during 2006-2007. Of these, 444 were randomly selected, and 453 were historic breeding blocks (37 of which were also randomly selected and were treated as random blocks in our analysis). During the course of this survey, we documented the exact locations of 1,758 Burrowing Owl pairs, and have provided this information to the California Department of Fish and Game for their conservation planning purposes.

INDIVIDUAL REGIONS

NORTHERN CENTRAL VALLEY

We surveyed 33 randomly-selected and 15 historic breeding blocks in this region (Fig. 2). We detected no burrowing owls in the random blocks and 10 pairs in the historic breeding blocks; 2 pairs were incidentally detected outside our targeted blocks. All pairs were detected on lowland blocks in Tehama and Yuba counties.

Our random-sample based population estimate for this region is zero. Using our criteria stated earlier, the "best estimate" is 12 pairs for the lowland subregion and zero for upland subregion. The number of Burrowing Owl pairs detected in the region declined only moderately, from 18 pairs to 12 pairs between the 1991-1993 and 2006-2007 surveys, but because 11 pairs were found on randomly-selected blocks during 1991-1993 (compared to no owls detected on randomly-selected blocks during 2006-2007), DeSante et al. (2007) extrapolated their early 1990s findings to estimate that 231 pairs were present in the region, a number greatly in excess of both our estimate of zero pairs extrapolated from random blocks only ($\chi^2_1 = 4.274$, $P = 0.039$; Table 3) and our "best estimate" of 12 pairs, reflecting the actual number of pairs we detected on all blocks surveyed (Table 4).

MIDDLE CENTRAL VALLEY

We surveyed 71 randomly-selected blocks and 128 historic breeding blocks in this region (Fig. 3). Surveys of random blocks yielded 34 Burrowing Owl pairs, and surveys of historic breeding blocks yielded 348 pairs, for a total of 382 pairs. Substantial concentrations of owls were located in lowland areas of Yolo, Solano, Sacramento, Contra Costa, and San Joaquin counties. However we found only two pairs in all of Stanislaus County, and detected only one pair incidentally in Merced County. We found no Burrowing Owls in the upland (foothill) blocks of western El Dorado, Amador, Calaveras, Tuolumne, and Merced counties.

In the 59 randomly-selected lowland blocks surveyed, we found 34 owl pairs, yielding a random-sample based estimate of 502 ± 209 pairs. This estimate was greater than the total number of pairs we actually found in the lowland subregion (34 pairs on randomly-selected blocks plus 305 pairs on historic breeding blocks), so it serves as our "best estimate" for the upland subregion. No owls were detected on randomly-selected upland blocks anywhere in the region, so our random-sample based estimate for the upland subregion is zero pairs. However, we found 43 pairs on upland historic breeding blocks, so our "best estimate" for the upland subregion is the actual number of pairs we found in upland blocks: 43 pairs. Summing our estimate of 502 ± 209 pairs in the lowland subregion and our count of 43 pairs on the upland blocks surveyed, our estimate for the Middle Central Valley region is 545 pairs, 8.2% fewer than the 594 pairs DeSante et al. (2007) estimated to be present in the early 1990s (Table 4).

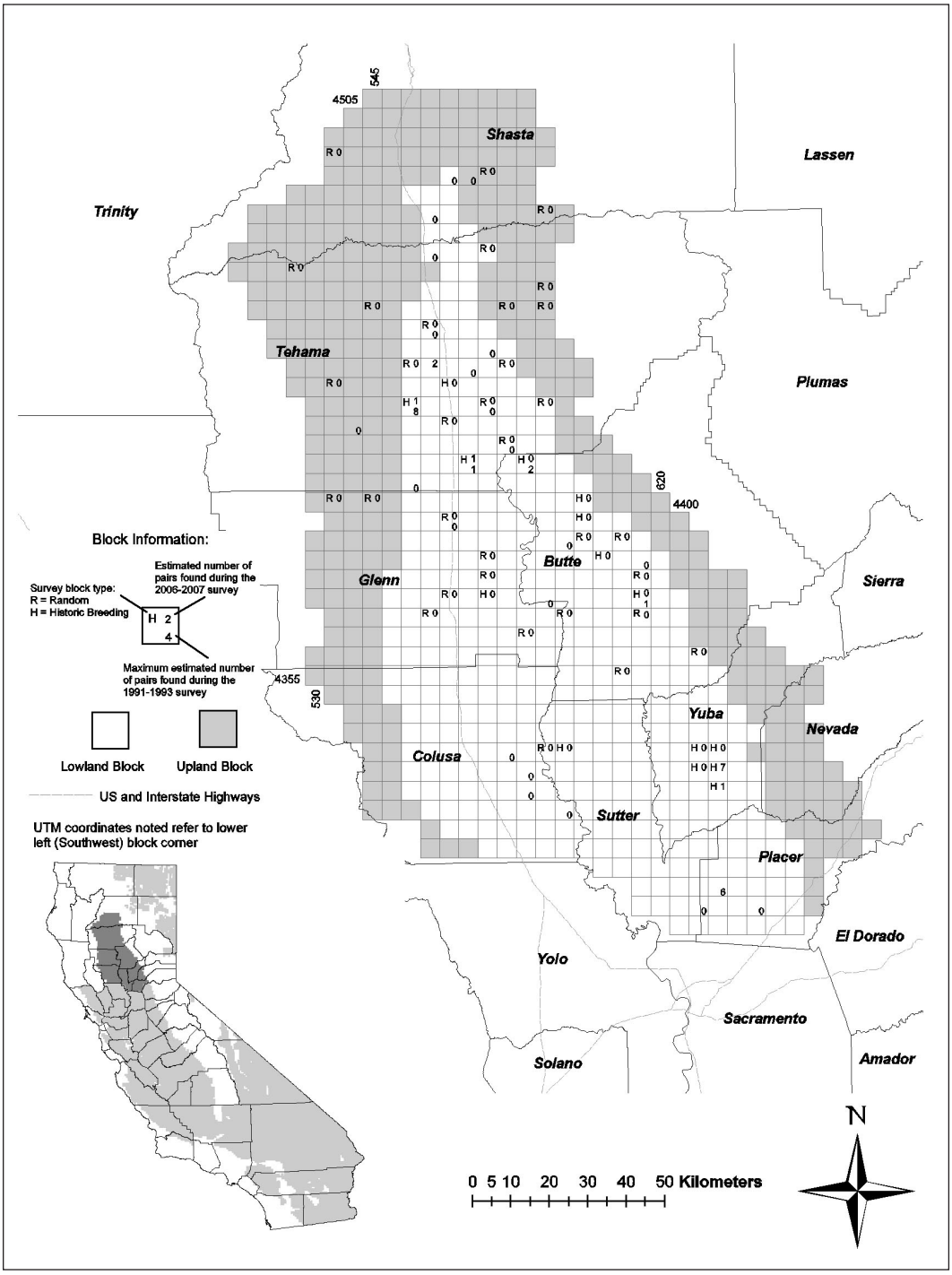

FIGURE 2. Results from the Northern Central Valley region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the Northern Central Valley region are shown in the inset.

TABLE 3. Comparison of Burrowing Owl regional population estimates extrapolated from randomly-selected blocks for regions that were surveyed during both the 1991-1993 and 2006-2007 surveys. Although we present extrapolated population estimates for all regions here, in many cases the extrapolated number of pairs based on random blocks only was not judged to be the "best estimate" of the regional population.

	1991-1993 survey		2006-2007 survey			
Region	No. of random blocks surveyed	Extrapolated no. of pairs (SE)	No. of random blocks surveyed	Extrapolated no. of pairs (SE)	Change in estimated no. of pairs	Percent change in estimated no. of pairs
Northern Central Valley						
Lowland	22	231 (153)	22	0	-231	-100%
Upland	2	0	11	0	0	n/a
All	24	231 (153)	33	0	-231	-100%
Middle Central Valley						
Lowland	163	577 (122)	59	502 (209)	-75	-13.0%
Upland	28	17 (17)	12	0	-17	-100%
All	191	594 (139)	71	502 (209)	-92	-15.5%
Southern Central Valley						
Lowland	41	1,000 (410)	63	968 (342)	-32	-3.2%
Upland	11	396 (182)	18	145 (118)	-251	-61.4%
All	52	1,396 (592)	81	1,113 (460)	-283	-20.3%
Entire Central Valley	267	2,221 (884)	185	1,615 (669)	-606	-27.3%
San Francisco Bay Area Interior						
Lowland	86	41 (20)	20	0	-41	-100%
Upland	25	0	12	21 (21)	+21	n/a
All	111	41 (20)	32	21 (21)	-20	-51.2%
Central-western Interior						
Lowland	14	0	17	0	0	n/a
Upland	16	31 (27)	13	76 (51)	+45	+145.2%
All	30	31 (27)	30	76 (51)	+45	+145.2%
Southwestern Interior						
Lowland	4	100 (100)	3	17 (17)	-83	-83%
Upland	10	127 (81)	8	0	-127	-100%
All	14	227 (181)	11	17 (17)	-210	-95.2%
Coachella Valley						
Lowland	5	0	4	16 (16)	+16	n/a
Upland	6	0	4	0	0	n/a
All	11	0	8	16 (16)	+16	n/a
Imperial Valley						
Lowland	15	6,429 (1,135)	5	5,701 (2,244)	-728	-11.32%
Upland	1	142	2	707 (140)	+565	+397.9%
All	16	6,577	7	6,408 (2,384)	-163	-2.6%

SOUTHERN CENTRAL VALLEY

We surveyed 81 randomly-selected blocks and 83 historic breeding blocks in this region (Fig. 4). Surveys of random blocks yielded 75 Burrowing Owl pairs, and surveys of historic breeding blocks yielded 161 pairs, for a total of 236 pairs.

Owls were considerably more abundant in the southern portion of this region than in the northern portion. We found Burrowing Owls in only one survey block in Madera County (though it had 12 pairs), and our detections were nearly as sparsely distributed in Fresno and Kings counties. We found substantial concentrations only in Tulare and Kern counties. As in the other Central Valley regions, the great majority of owls we found were in lowland blocks; in the upland blocks covering the Sierra foothills we found owls in just one block in each

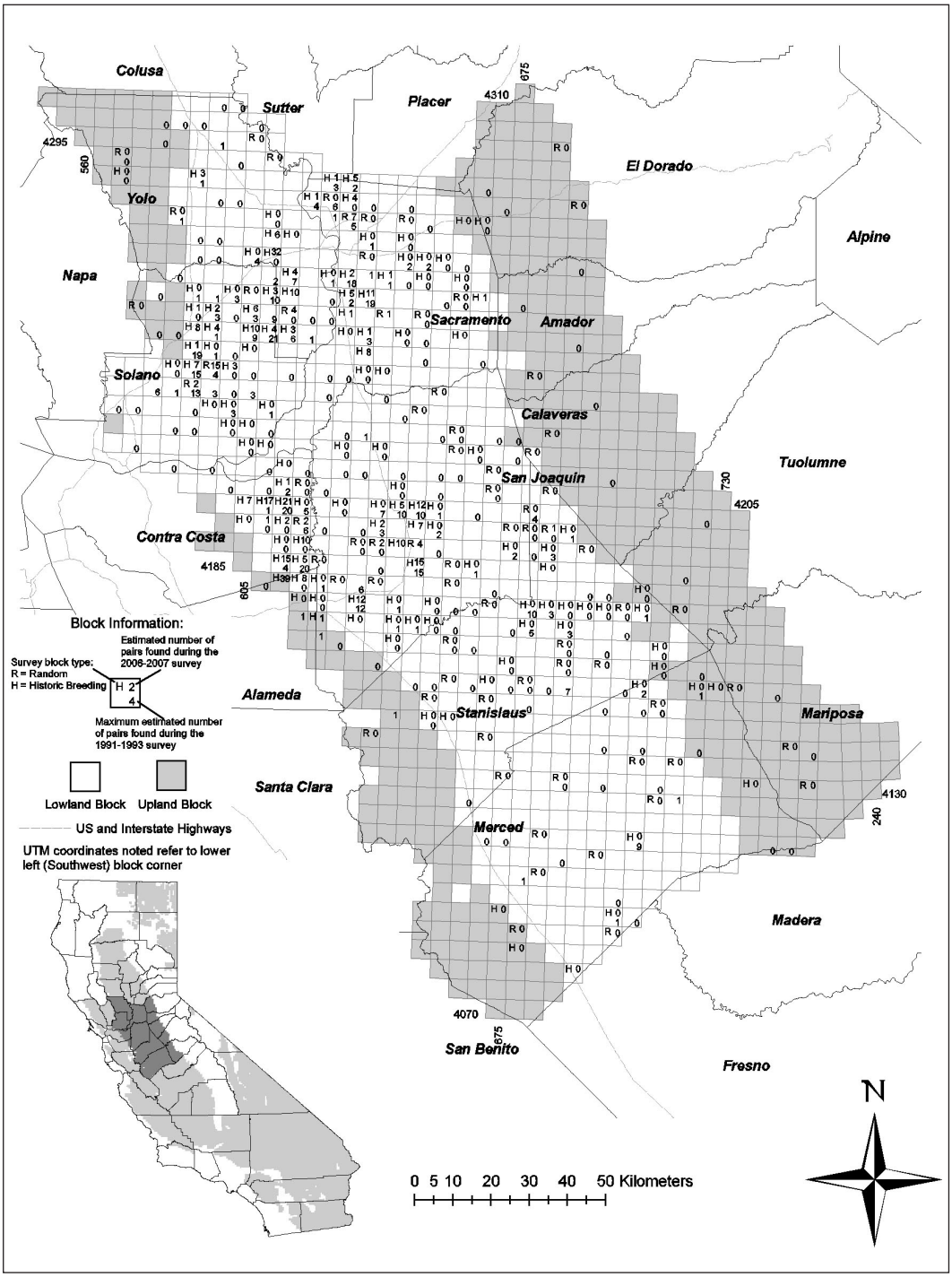

FIGURE 3. Results from the Middle Central Valley region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the Middle Central Valley region are shown in the inset.

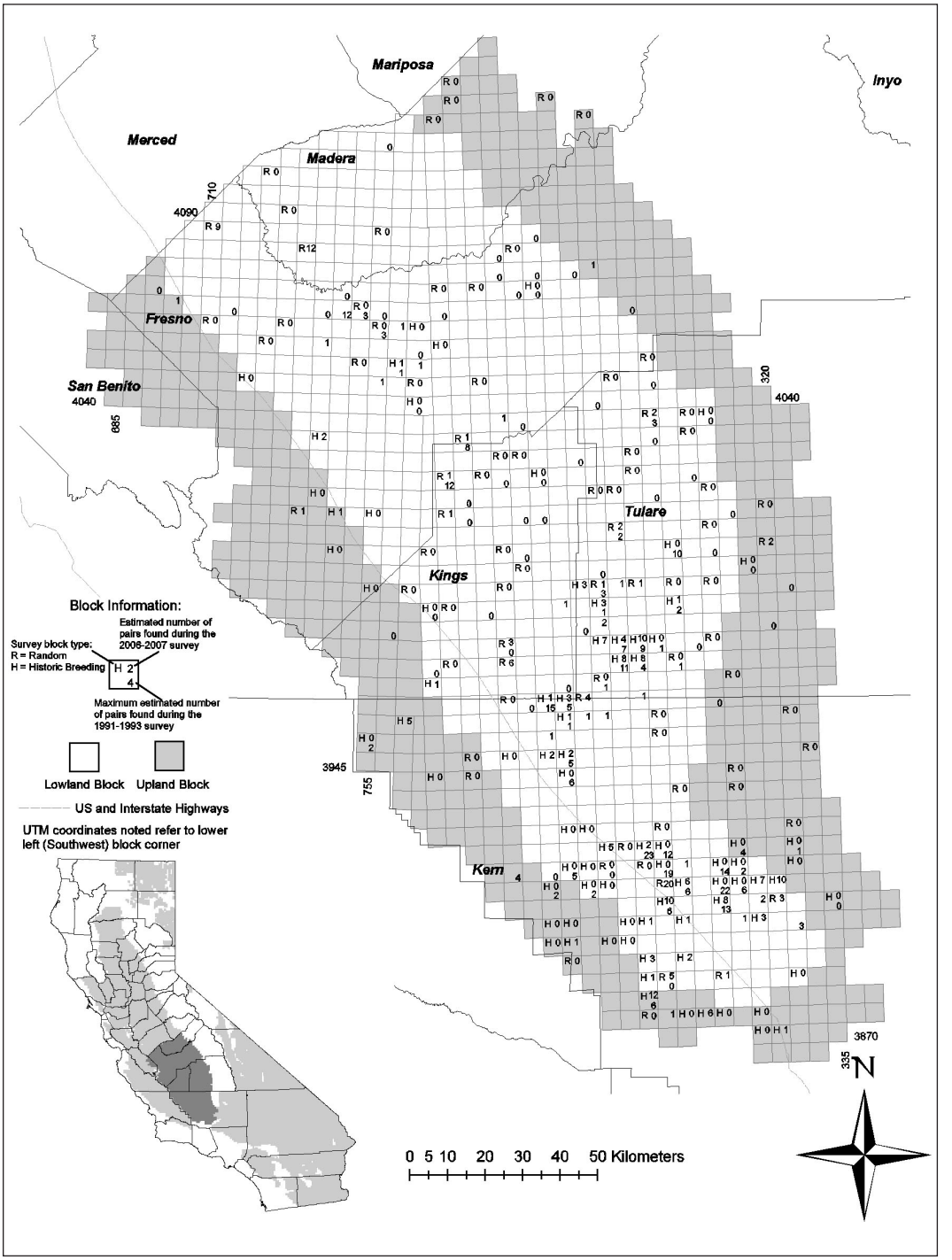

FIGURE 4. Results from the Southern Central Valley region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the Southern Central Valley region are shown in the inset.

TABLE 4. Comparison of regional and statewide "best estimates" of population size from the 1991-1993 and 2006-2007 Burrowing Owl surveys.

	1991-1993 survey		2006-2007 survey			
Region	No. of pairs found	"Best estimate" of pairs in region[a]	No. of pairs found	"Best estimate" of pairs in region[a]	Change in estimated no. of pairs	Percent change in estimated no. of pairs
Northern Central Valley						
Lowland	18	231 (153)	12	12	-219	-94.8%
Upland	0	0	0	0	0	n/a
All	18	231 (153)	12	12	-219	-94.8%
Middle Central Valley						
Lowland	404	577 (112)	339	502 (209)	-75	-13.0%
Upland	1	17 (17)	43	43	+26	+152.9%
All	405	594 (129)	382	545	-49	-8.2%
Southern Central Valley						
Lowland	259	1,000 (410)	204	968 (342)	-32	-3.2%
Upland	19	396 (182)	32	145 (118)	-251	-63.4%
All	278	1,396 (592)	236	1,113 (460)	-283	-20.3%
San Francisco Bay Area Interior						
Lowland	154	154	98	98	-56	-36.4%
Upland	11	11	21	21	+10	+90.9%
All	165	165	119	119	-46	-27.9%
San Francisco Bay Area Coast[b]						
Lowland	0	0	0	0	0	n/a
Upland	0	0	0	0	0	n/a
All	0	0	0	0	0	n/a
Central-western Interior						
Lowland	7	7	8	8	+1	+14.3%
Upland	3	31 (27)	13	76 (51)	+45	+145.2%
All	10	38	21	84	+46	+121.1%
Central-western Coast[c]						
Lowland	8	8	0	0	-8	-100%
Upland	0	0	0	0	0	n/a
All	8	8	0	0	-8	-100%
Southwestern Coast[d]						
Lowland	8	36 (36)	16	16	-20	-55.6%
Upland	0	0	26	26	+26	n/a
All	8	36 (36)	42	42	+6	+16.7%
Southwestern Interior						
Lowland	12	100 (100)	37	37	-63	-63%
Upland	6	127 (81)	113	113	-14	-11.0%
All	18	227 (181)	150	150	-77	-33.9%
Coachella Valley						
Lowland	0	0	12	16 (16)	+16	n/a
Upland	0	0	37	37	+37	n/a
All	0	0	49	53	+53	n/a
Imperial Valley						
Lowland	1,041	6,429 (1,135)	499	5,701 (2,244)	-728	-11.3%
Upland	4	142	22	707 (140)	+565	+397.9%
All	1,045	6,571	521	6,408 (2,384)	-163	-2.5%
Modoc Plateau/Great Basin						
All	Not surveyed		0	0	n/a	n/a
Northern Mojave/Eastern Sierra Nevada[e]						
Lowland	Not surveyed		1	1	n/a	n/a
Upland	Not surveyed		0	0	n/a	n/a
All	Not surveyed		1	1	n/a	n/a

TABLE 4. Continued.

Region	1991-1993 survey		2006-2007 survey			
	No. of pairs found	"Best estimate" of pairs in region[a]	No. of pairs found	"Best estimate" of pairs in region[a]	Change in estimated no. of pairs	Percent change in estimated no. of pairs
Western Mojave Desert[e]						
Lowland	Not surveyed		94	560 (268)	n/a	n/a
Upland	Not surveyed		0	0	n/a	n/a
All	Not surveyed		94	560 (268)	n/a	n/a
Eastern Mojave Desert[e]						
Lowland	Not surveyed		1	32 (32)	n/a	n/a
Upland	Not surveyed		0	0	n/a	n/a
All	Not surveyed		1	32 (32)	n/a	n/a
Sonoran Desert[e]						
All	Not surveyed		179	179	n/a	n/a
Statewide, excluding "new" regions						
Number of pairs found	1,955		1,532		-423	-21.6%
Extrapolated no. of pairs		9,127 (1,243)		8,128 (2,391)	-999	-10.9%
"Best estimate" of no. of pairs		9,266		8,526	-740	-8.0%
Statewide, including "new" regions						
Number of pairs found			1,758			
Extrapolated no. of pairs				9,187 (2,346)		
"Best estimate"				9,298		

[a] Numbers in parenthesis indicate the standard error of the estimate. Estimates lacking a standard error indicate the actual count of breeding pairs detected in a subregion and are presented as the "best estimate" in cases where the count is higher than the region's calculated population estimate, which is based on randomly-selected blocks only and excludes data from historic breeding blocks that were not randomly selected

[b]The San Francisco Bay Area Coast region was not surveyed as part of this study in 2006-2007. Our "best estimate" of zero pairs in both the lowland and upland subregions is based on local knowledge (D. DeSante, *pers. comm.*) and information in Townsend and Lenihan (2007).

[c]The Central-western Coast region was not surveyed as part of this study in 2006-2007. Our "best estimate" of zero pairs in both the lowland and upland subregions is based on local knowledge (D. Roberson, *pers. comm.*).

[d]The Southwestern Coast region was not surveyed as part of this study in 2006-2007. Our "best estimates" of 16 pairs in the lowland subregion and 26 pairs in the upland subregion are based on information in Lincer and Bloom (2007) and Kidd et al. (2007).

[e]Reported in Wilkerson and Siegel (*in press*).

of Fresno, Tulare, and Kern counties.

In the 63 randomly-selected lowland blocks surveyed, we found 72 pairs of owls, yielding a random-sample based estimate of 968 ± 342 pairs. This estimate was greater than the total number of pairs found in the lowland subregion (72 pairs on randomly-selected blocks plus 132 pairs on historic breeding blocks), so it serves as our "best estimate" for the lowland subregion. In the 18 randomly-selected upland blocks surveyed, we found three pairs of owls, yielding a random-sample based estimate of 145 ± 118 pairs in the upland subregion. This estimate is greater than the total number of pairs found in the upland subregion (three pairs on randomly-selected blocks plus 32 pairs on historic breeding blocks), so it serves as our "best estimate" for the upland subregion. Summing our extrapolated estimates for the lowland and upland subregions, our estimate for the Southern Central Valley region is 1,113 ± 460 pairs (Table 3), 20.3 % fewer than the 1,396 pairs DeSante et al. (2007) estimated in the early 1990s (Table 4), but not a statistically significant difference ($F_{1,131}$ = 0419, P = 0.838).

Examining blocks that contained Burrowing Owls in the early 1990s and were resurveyed during 2006-2007 indicates two areas in the region where substantial, concentrated losses appear to have occurred: six blocks in western

Bakersfield lost a total of 53 breeding pairs, and further west, in agricultural land located west of Rosedale and south of Shafter, 42 fewer pairs were detected on three survey blocks (Fig. 5). Concentrated losses of Burrowing Owls on the western edge of Bakersfield occurred in blocks where substantial urban land conversion occurred between 1992 and 2001 (Multi-resolution Land Characteristics Consortium 2001).

SAN FRANCISCO BAY AREA INTERIOR

We surveyed 32 randomly-selected blocks and 58 historic breeding blocks in this region (Fig. 6). The relatively large proportion of historic breeding blocks reflects the excellent pre-survey information available about the region's Burrowing Owls. Surveys of random blocks yielded only a single pair, located on an upland block in northeastern Alameda County, north of Livermore. Pooling data from random and historic breeding blocks, we found 119 pairs.

All of the Burrowing Owls detected in the region were in Alameda or Santa Clara counties. During the 1990s survey small numbers of Burrowing Owl pairs were also detected in San Mateo County (one pair) and Sonoma County (two pairs), but our surveyors were unable to find owls in these or other locations throughout those counties.

In Alameda County, we detected no Burrowing Owls in the western, lowland portion adjacent to San Francisco Bay, where 34 pairs were found distributed across nine blocks in the early 1990s (Fig. 7). In contrast, we found 14 pairs of owls in the upland blocks of the eastern half of the county (compared with 11 pairs found in the early 1990s) along the Highway 580 corridor between Dublin and Livermore and in the Altamont Hills northeast of Livermore, an area where relatively large numbers of breeding Burrowing Owls have recently been observed (Barclay and Harman 2007). The richest area in Alameda County was the south-central lowland portion; we observed 25 pairs on a single block at Don Edwards San Francisco Bay National Wildlife Refuge. Two pairs were detected on the same block during the 1991-1993 survey. Nine additional pairs were distributed across two historic breeding blocks to the north of this area, apparently in urban park or industrial yard settings in the cities of Fremont and Newark.

In Santa Clara County, detections were restricted to the lowland area in the northwestern corner, as they were during the early 1990s. We detected 56 pairs on two blocks in San Jose and two blocks in Mountain View (Fig. 7), reduced from 97 pairs in the early 1990s.

We detected no pairs on randomly-selected lowland blocks anywhere in the San Francisco Bay Area Interior region, resulting in a zero population estimate for the lowland subregion. We detected 98 pairs on lowland historic breeding blocks, resulting in our "best estimate" of 98 pairs for the lowland subregion. On the 12 randomly-selected upland blocks surveyed, we found one owl pair, yielding a random-sample based estimate of 21 ± 21 pairs throughout the upland subregion. This estimate was greater than the total number of pairs we found on surveyed blocks in the upland subregion (one pair on randomly-selected blocks plus 13 pairs on historic breeding blocks), so it serves as our best estimate for owl pairs in the upland subregion. Summing our count from the lowland blocks and our estimate in the upland subregion, our "best estimate" for the number of Burrowing Owl pairs in the San Francisco Bay Area Interior region is 119. This estimate represents a nearly 28% reduction from the 165 pairs estimated from the 1991-1993 survey (Table 4). Like our estimate, the early 1990s estimate was also an actual count of all pairs found, rather than an extrapolated estimate based on randomly-selected blocks only, so the statistical significance of the apparent decline cannot be tested. However, because the region is very well known by the local birding community (which helped us identify historical breeding blocks), it seems unlikely that there could be more than a few pairs that went undetected during either survey.

SAN FRANCISCO AREA COAST

DeSante et al. (2007) were unable to find any Burrowing Owls in this region during the 1990s survey (Table 4). This relatively small region is well-monitored and well-known by the local birding community. We did not resurvey the region for the 2006-2007 study, as consultation with local experts as well as information in Townsend and Lenihan (2007) strongly indicates that the species remains extirpated from the region.

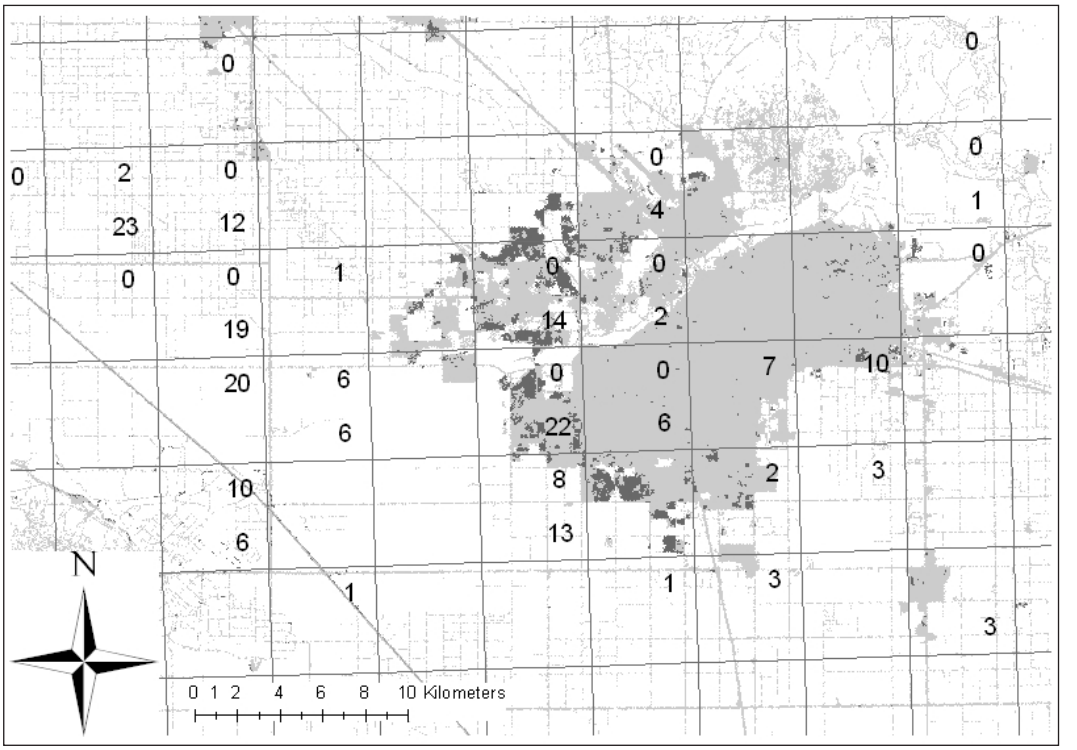

FIGURE 5. The number of Burrowing Owl pairs detected in the Bakersfield area during IBP's 1991-1993 survey (indicated in lower right corner of each block) and 2006-2007 survey (indicated in upper right corner of survey block). The large shaded area represents metropolitan Bakersfield; light gray shading indicates urban land cover as of 1992; dark gray shading indicates areas that were not mapped as urban in 1992, but were converted to urban use between 1992 and 2001 (Multi-resolution Land Characteristics Consortium 2001). Note the concentrated losses of Burrowing Owls in blocks on the western edge of Bakersfield, where substantial urban land conversion occurred between 1992 and 2001.

CENTRAL-WESTERN INTERIOR

We surveyed 30 randomly-selected blocks and 14 historic breeding blocks in this region (Fig. 8). Surveys of random blocks yielded just two Burrowing Owl pairs, both located on upland blocks of San Luis Obispo County. Pooling data from random and historic breeding blocks, we found 21 pairs in the region. Small clusters of owls were found in four areas: Bolsa Valley northwest of Hollister, San Benito County; low foothills of the Coast Range east of King City, Monterey County; northeast corner of San Luis Obispo County; and the Carrizo Plain, southeastern San Luis Obispo County (Fig. 8).

Since no Burrowing owls were detected on randomly-selected lowland blocks anywhere in this region, our random-sample based population estimate for the lowland subregion is zero pairs. However, we found 8 pairs on lowland historic breeding blocks, so our "best estimate" for the lowland subregion is the actual number of pairs we found: eight. On the 13 randomly-selected upland blocks we surveyed, we found two pairs, yielding a random-sample based estimate of 76 ± 51 pairs throughout the upland subregion. This estimate was greater than the total number of pairs we found in the upland subregion (two pairs on randomly-selected blocks plus 11 pairs on historic breeding blocks), so it serves as our best estimate for owl pairs in the upland subregion. Summing our count on the lowland blocks and our estimate in the upland subregion, our estimate for the Central-western Interior region is 84 pairs, a 121% increase from the estimate of 38 pairs during the 1991-1993 survey (Table 4).

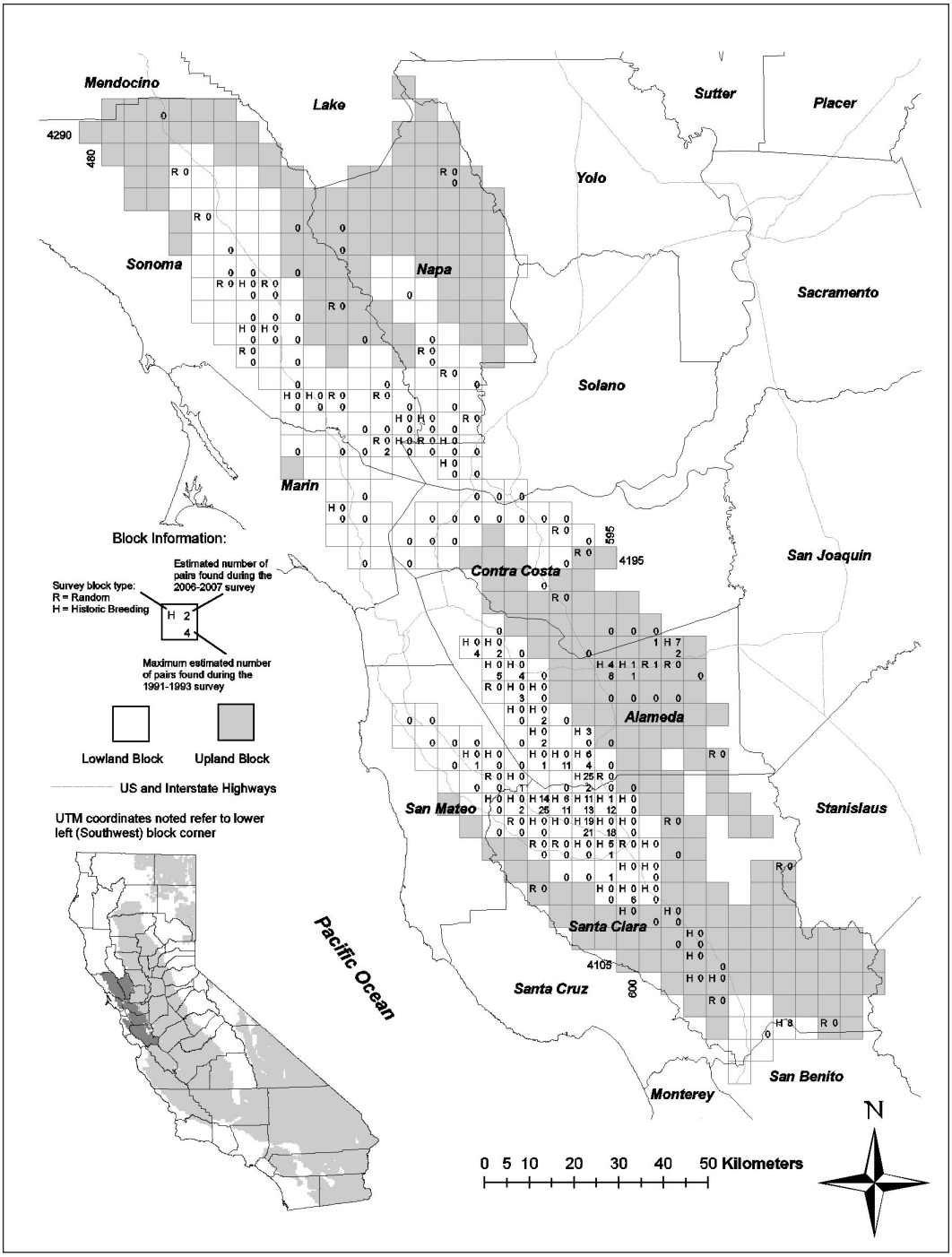

FIGURE 6. Results from the San Francisco Bay Area Interior region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the San Francisco Bay Area Interior region are shown in the inset.

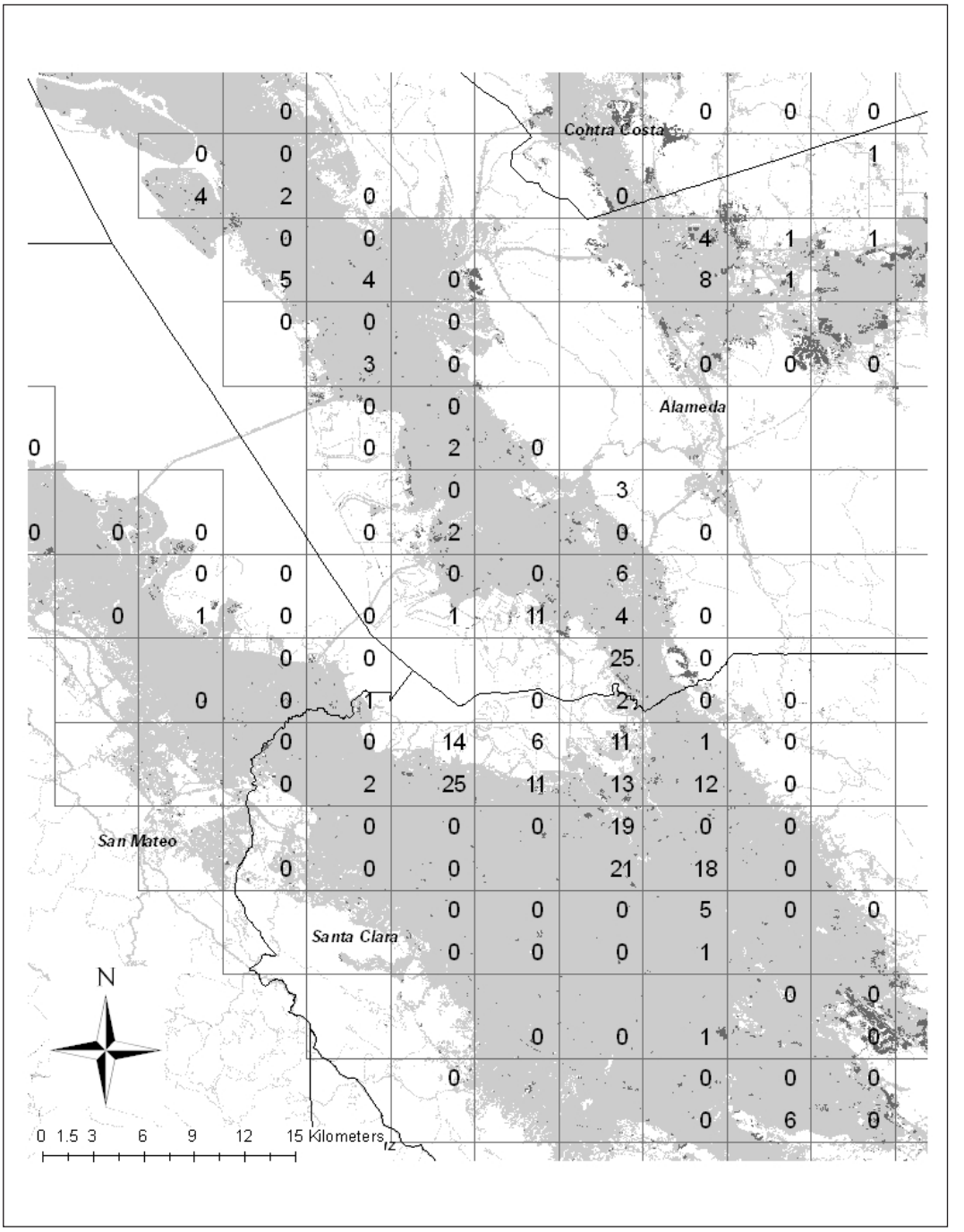

FIGURE 7. The number of Burrowing Owl pairs detected on survey blocks in the southern and eastern San Francisco Bay Area during IBP's 1991-1993 survey (indicated in lower right corner of each block) and 2006-2007 survey (indicated in upper right corner of survey block). Light gray shading indicates urban land cover as of 1992; dark gray shading indicates areas that were not mapped as urban in 1992, but were converted to urban use between 1992 and 2001 (Multi-resolution Land Characteristics Consortium 2001).

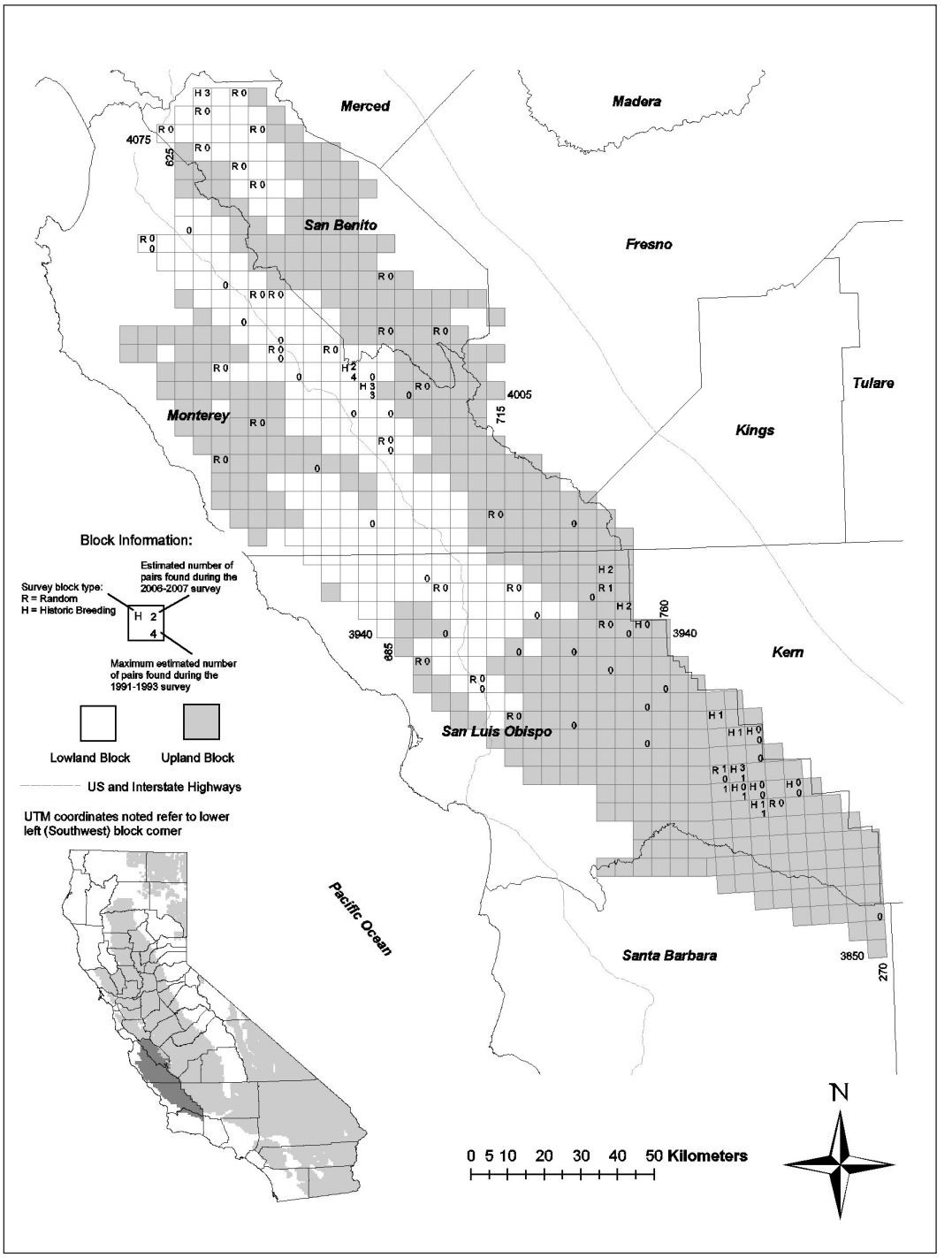

FIGURE 8. Results from the Central-western Interior region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the Central-western Interior region are shown in the inset

CENTRAL-WESTERN COAST

This is one of the three coastal regions we did not survey during 2006-2007. In the 1991-1993 survey, eight pairs of Burrowing Owls were detected in the region; seven pairs were near Salinas, Monterey County, and a single pair was in northern Santa Barbara County (DeSante et al. 2007). The Salinas owls were distributed between two areas; five pairs were at the Salinas Airport and two pairs were near the town of Boronda. Visits to both of those sites by local birders in the last decade have yielded no detections, and foraging habitat adjacent to the airport colony has been developed (D. Roberson, *pers. comm.*). The single pair from northern Santa Barbara County was present in 1992, but could not be relocated when the same survey block was revisited in 1993 (DeSante et al. 2007). Consequently Burrowing Owls are likely extirpated from the region (Table 4).

SOUTHWESTERN COAST

Because the few breeding owls present in this region are already well monitored, we did not survey the region. Kidd et al. (2007) determined that Burrowing Owl populations in western Santa Barbara, Ventura, and Los Angeles counties had been extirpated; however, they documented three breeding pairs in Orange County as recently as 2005. In a thorough assessment of the species' status in San Diego County, Lincer and Bloom (2007) determined there were between 41 and 46 pairs present; all but two were within our region boundaries, allowing for a count of between 39 and 44 pairs. The lower count of 39 plus the three pairs from Orange County yields an estimate of 42 pairs for the Southwestern Coast region (Table 4). The 1991-1993 "best estimate" for this region was 36 pairs, although only eight pairs were actually detected (DeSante et al. 2007). The apparent increase could be from the more thorough coverage provided by Lincer and Bloom (2007) or a slight but real increase in the region's owl population.

SOUTHWESTERN INTERIOR

We surveyed 11 randomly-selected blocks and 57 historic breeding blocks in this interior region (Fig. 9). The relatively large proportion of historic breeding blocks reflects the excellent pre-survey information we received from a UC Riverside graduate student studying the local Burrowing Owl population (Ginny Short, *pers. comm.*). Our surveys of random blocks yielded only a single pair, located in a lowland block at Ontario International Airport, San Bernardino County. However, we found 149 pairs utilizing diverse habitats on historic breeding blocks, yielding a total of 150 pairs of owls detected in the region.

The one pair of owls found on the three randomly-selected lowland blocks yielded a random-sample based estimate of 17 ±17 pairs throughout the lowland subregion. Since this estimate was lower than the total number of pairs found in the lowland subregion (pooling data detections from random and historic breeding blocks) our "best estimate" for the number of owl pairs in the lowland subregion is the actual number of pairs counted: 37. Since no Burrowing Owls were detected on any of the eight randomly-selected upland blocks, our random-sample based estimate for the upland subregion is zero pairs. However, we found 113 pairs on upland historic breeding blocks, so our best estimate for the upland subregion is the actual number of pairs found: 113. Summing our counts from lowland and upland blocks, our estimate for the Southwestern Interior region is 150 pairs, 33.9% fewer than were estimated to be present during the 1991-1993 survey (Table 4). We note, however, that the 1990s estimate was extrapolated from surveys of random blocks while our estimate is our actual count of all owls on random and historic breeding blocks, and was based on more extensive pre-survey information. Thus, comparing these "best estimates" may be somewhat problematic.

COACHELLA VALLEY

We surveyed eight randomly-selected blocks and 12 historic breeding blocks in this region (Fig. 10). Surveys of random blocks yielded just one pair of Burrowing Owls, while surveys of historic breeding blocks yielded 48 pairs, for a total of 49 pairs detected in the region. The highest densities of detections were clustered at the northern end of the region around the town of Desert Hot Springs and south to Interstate 10. Smaller numbers of owls (1-4 pairs per block) were detected along the Interstate 10 corridor as far south as the town of Mecca. A single pair was located on a randomly-selected block along

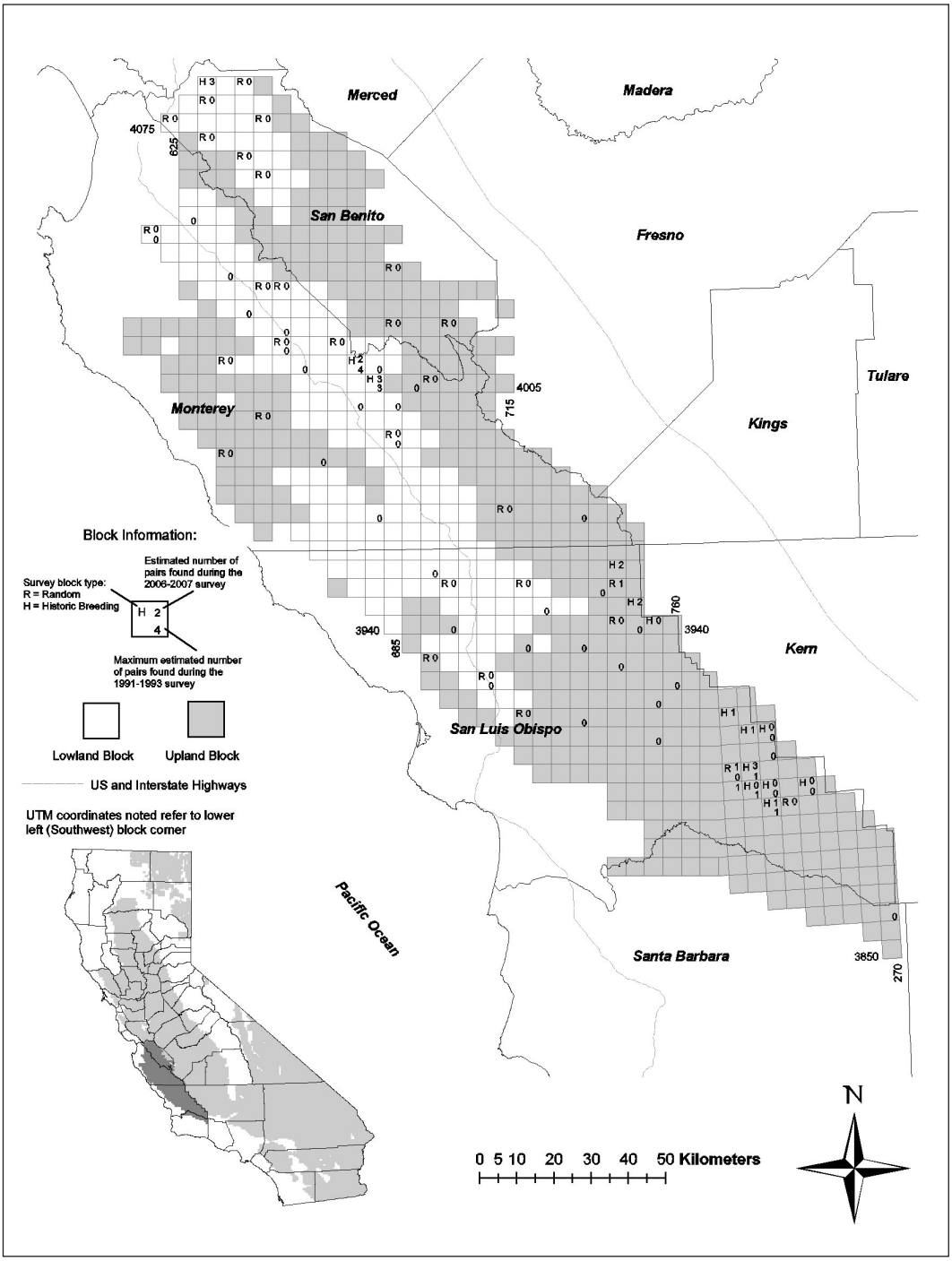

FIGURE 9. Results from the Southwestern Interior region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the Southwestern Interior region are shown in the inset.

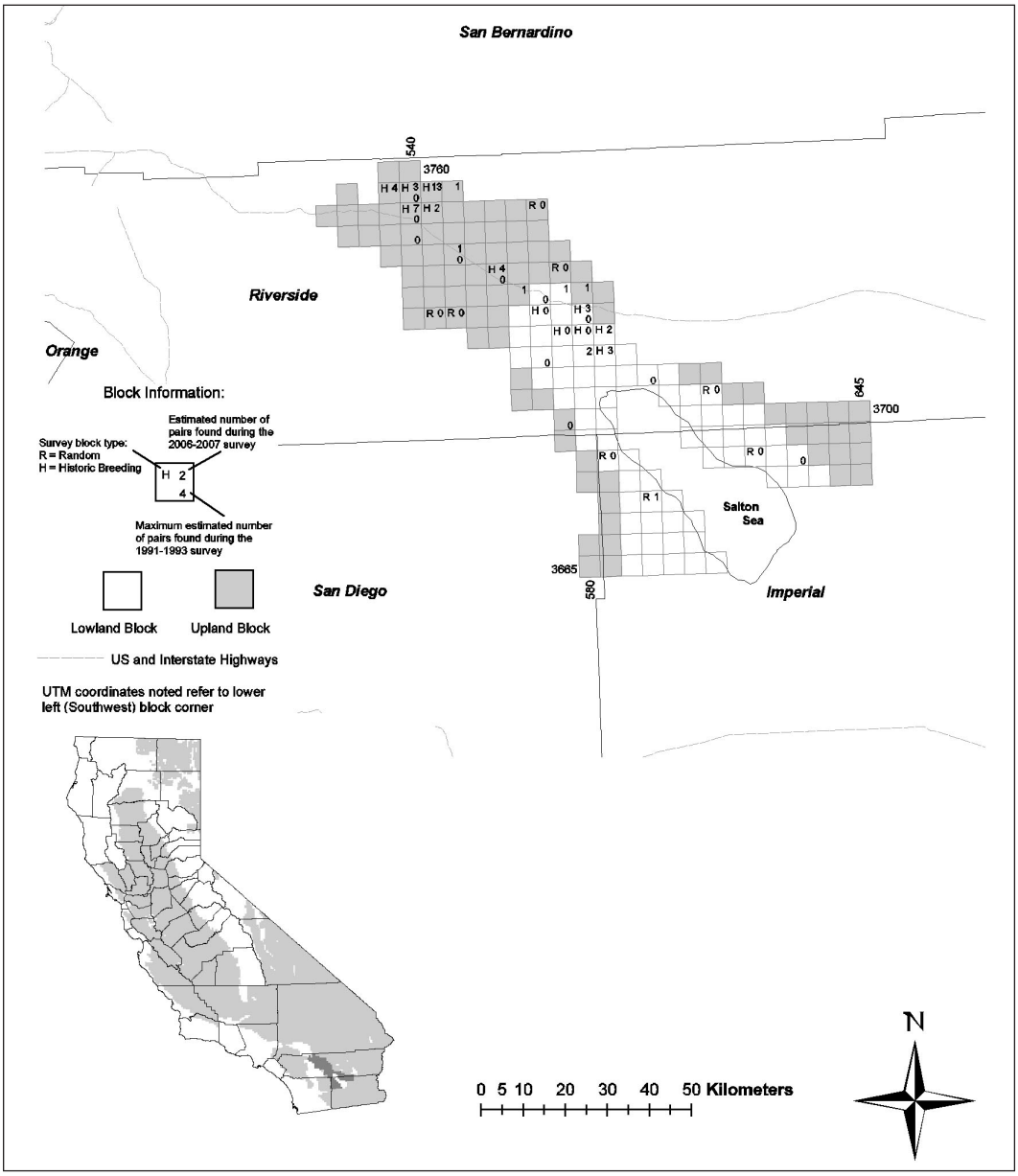

FIGURE 10. Results from the Coachella Valley region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the Coachella Valley region are shown in the inset.

the west side of the Salton Sea, at the southern end of Salton City.

In the four randomly-selected lowland blocks surveyed, we found one pair of owls, yielding a random-sample based estimate of 16 ± 16 pairs throughout the lowland subregion. This estimate was slightly greater than the total number of pairs found in the lowland subregion (one pair on randomly-selected blocks plus 11 pairs on historic breeding blocks), so it serves as

our "best estimate" for owl pairs in the lowland subregion. No Burrowing Owls were detected on the four randomly-selected upland blocks, so our random-sample based population estimate for the upland subregion is zero pairs. However, we found 37 pairs on upland historic breeding blocks, so our "best estimate" for the upland subregion is the actual number of pairs we found: 37. Summing our estimate from the lowland subregion and our count on the upland blocks surveyed, our estimate for the Coachella Valley region is 53 pairs, a remarkable change from the 1991-1993 estimate of zero pairs (Table 4). Four historic breeding blocks (two upland blocks at the northern end of the region plus an additional upland and lowland block further south), in which we found multiple pairs, were also surveyed in the early 1990s (then also selected as random blocks), when no owls were detected. These results suggest the blocks may have been colonized since the 1991-1993 survey.

IMPERIAL VALLEY

We surveyed seven randomly-selected blocks and eight historic breeding blocks in this region (Fig. 11). Surveys of random blocks yielded 271 Burrowing Owl pairs, and surveys of historic breeding blocks yielded 250 pairs, for a total of 521 pairs detected.

In the five randomly-selected lowland blocks surveyed, we found 254 pairs, yielding a random-sample based estimate of 5,701 ± 2,244 pairs throughout the lowland subregion. This estimate was greater than the total number of pairs found in the lowland subregion (254 pairs on randomly-selected blocks plus 245 pairs on historic breeding blocks), so it serves as our "best estimate" for pairs in the lowland subregion. In the two randomly-selected upland blocks surveyed, we found 17 pairs of owls, yielding a random-sample based estimate of 707 ± 140 pairs throughout the upland subregion. This estimate was greater than the number of pairs we found in the upland subregion (17 pairs in randomly-selected blocks plus five pairs in historic breeding blocks), so it serves as our "best estimate" in the upland subregion. Summing our estimates for the lowland and upland subregions, our estimate for the Imperial Valley region is 6,408 ± 2,384 pairs, 2.5% fewer than the 6,571 pairs estimated during the 1991-1993 survey (Table 4), a statistically insignificant decline ($F_{1,12} = 0.3163$, $P = 0.584$).

MODOC PLATEAU/GREAT BASIN

We surveyed 13 randomly-selected blocks, and two historic breeding blocks in this region (Fig. 12). All blocks surveyed were classified as upland blocks, because the entire bioregion lies well above the upper bound of the lower elevation zones for all of our other survey regions.

We detected no Burrowing Owls on random blocks or historic breeding blocks, so our "best estimate" for the number of pairs in the region is zero pairs. Subsequent to our survey, breeding has been observed in Sierra Valley as recently as 2009 (Richard Carlson, *pers. comm.*), although information is lacking to determine whether this breeding location was active during 2006-2007 when we conducted our field work.

NORTHERN MOJAVE DESERT/EASTERN SIERRA NEVADA

We surveyed 36 randomly-selected blocks and two historic breeding blocks in this region; none of them yielded Burrowing Owl detections. However, one pair was detected incidentally on an otherwise unsurveyed block (see Wilkerson and Siegel, *in press*, for additional details).

WESTERN MOJAVE DESERT

We surveyed 48 randomly-selected blocks and 19 historic breeding blocks in this region. Our "best estimate", based on 25 pairs of owls detected on 42 pairs of owls detected on the random blocks, is 560 ± 268 pairs (see Wilkerson and Siegel, *in press*, for additional details).

EASTERN MOJAVE DESERT

We surveyed 43 randomly-selected blocks and two historic breeding blocks in the Eastern Mojave Desert region. Our "best estimate" for the region, based on one pair of owls detected on the randomly-selected blocks, is 32 ± 32 pairs (see Wilkerson and Siegel, *in press*, for additional details).

SONORAN DESERT

We surveyed 31 randomly-selected blocks, and 16 historic breeding blocks in the Sonoran Desert region. Our "best estimate" for the region, based on 179 pairs of owls detected

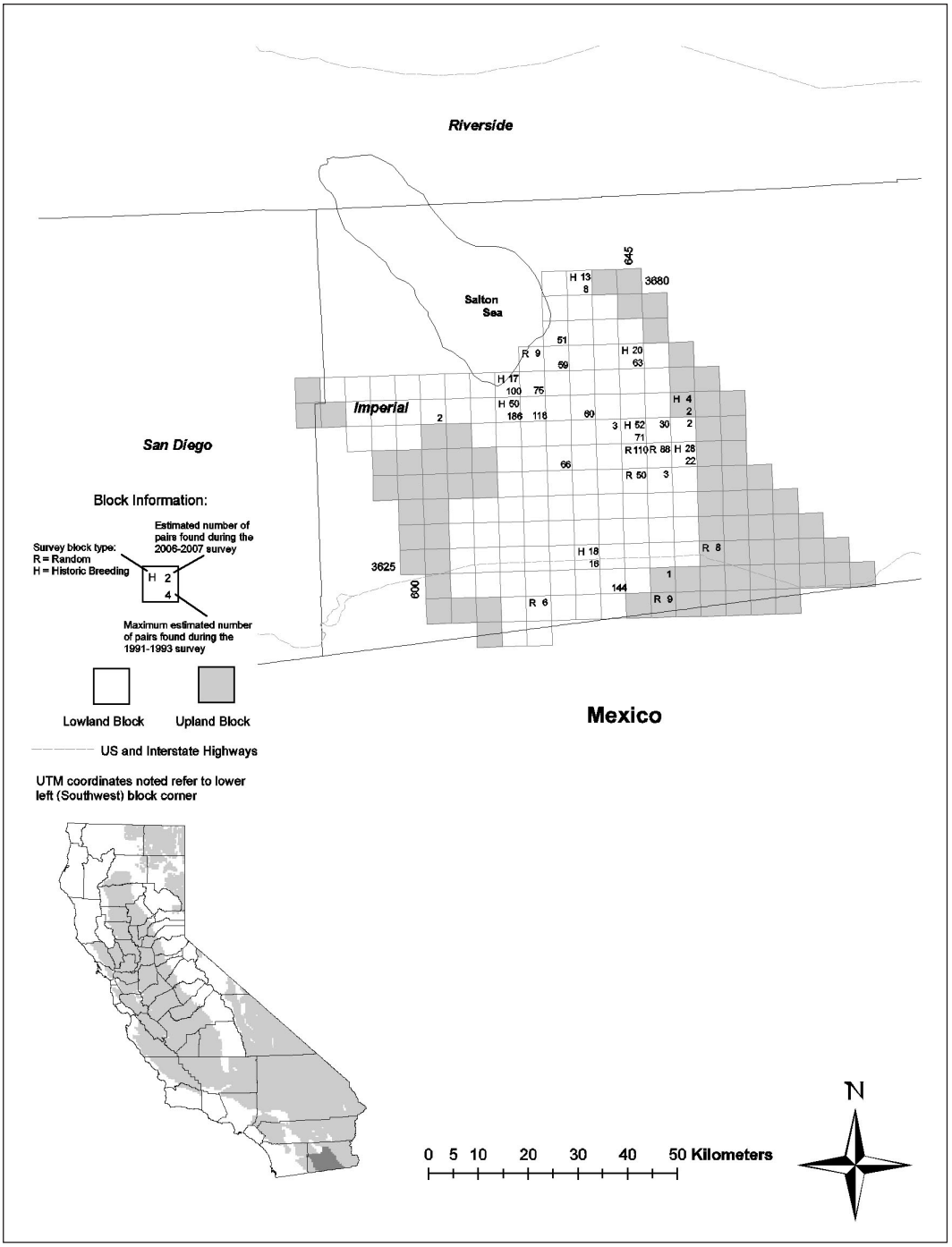

FIGURE 11. Results from the Imperial Valley region, including numbers of Burrowing Owl pairs detected during 1991-1993 and 2006-2007. Shown are all 5-km x 5-km lowland blocks (white) and upland blocks (gray) assigned to the region. The entire 2006-2007 survey area and the location of the Imperial Valley region are shown in the inset.

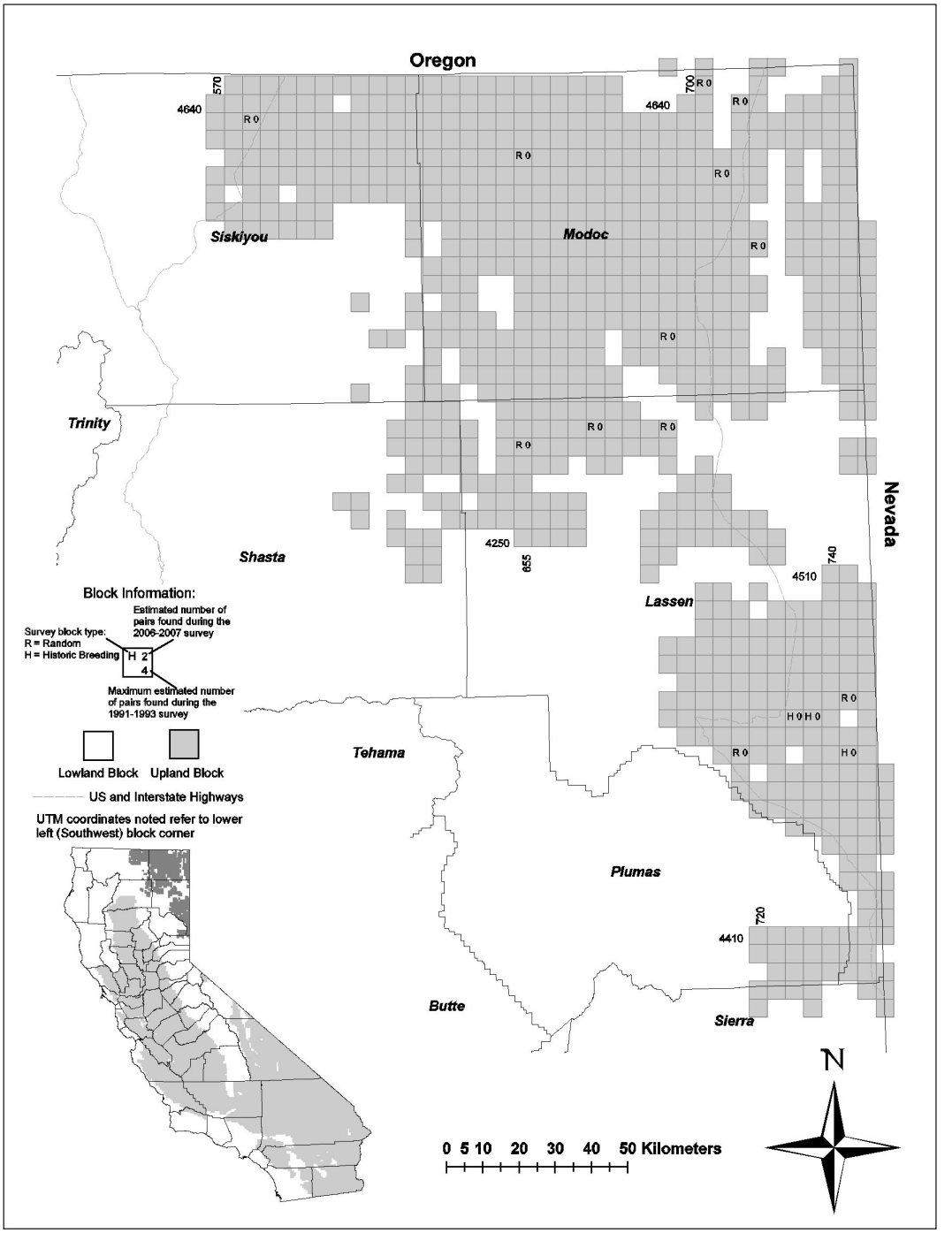

FIGURE 12. Results from the Modoc Plateau/Great Basin region of the 2006-2007 California Burrowing Owl survey. Shown are all 5-km x 5-km assigned to the region; in the case of this region, all blocks were classified as upland. The entire 2006-2007 survey area and the location of the Modoc Plateau/Great Basin region are shown in the inset.

exclusively within the Palo Verde Valley, and no owls detected elsewhere in the region, is our actual pair count in the Palo Verde Valley: 179 pairs (see Wilkerson and Siegel, *in press*, for additional details).

AGGREGATED STATEWIDE RESULTS

Aggregating results across all 2006-2007 survey regions yields a "best estimate" of 9,298 pairs of Burrowing Owls (Table 4). The population is highly concentrated in the Imperial Valley (68.9% of the California population) and to a lesser extent, the Southern Central Valley (12.0% of the statewide population) (Fig. 13). DeSante et al. (2007) reported very similar proportions of the estimated statewide population in 1991-1993 in these two regions.

Omitting the "new" survey regions (Modoc Plateau/Great Basin , Northern Mojave/Eastern Sierra Nevada, Western Mojave, Eastern Mojave, and Sonoran Desert), the aggregated "best estimate" for all regions that were previously surveyed in 1991-1993 is 8,526 pairs, 8% lower than the corresponding estimate generated from 1991-1993 (Table 4). Much of the apparent decline appears to be concentrated in two regions: the Northern Central Valley (231 pairs in 1991-1993 to 12 pairs in 2006-2007), and the Southern Central Valley (1,396 pairs in 1991-1993 to 1,113 pairs in 2006-2007). Other regions with reduced "best estimates" between 1991-1993 and 2006-2007 include the Middle Central Valley (-49 pairs), San Francisco Bay Interior (-46 pairs), Southwestern Interior (-77 pairs), and the Imperial Valley (-163 pairs, but the relatively high absolute numbers make this unlikely to be a meaningful change). In contrast to the overall pattern of declines, our 2006-2007 "best estimates" were higher than the corresponding 1991-1993 estimates for three regions: Central-western Interior (+46 pairs), Southwestern Coast (+6 pairs), and Coachella Valley (+53 pairs).

Because the statewide "best estimate" of the number of pairs is an aggregate of regional extrapolated population estimates and regional minimum counts there is no way to test the statistical significance of the apparent decline between 1991-1993 and 2006-2007. However, we can test for statistically significant change in our population estimates extrapolated only from surveys of randomly-selected blocks. DeSante et al. (2007) provided an extrapolated estimate of 9,127 ± 1,243 pairs for their entire study area; our 2006-2007 estimate extrapolated from randomly-selected blocks across the same survey regions is 8,128 ± 2,391 pairs (Table 4), a non-significant ($F_{1,710} = 0.0533$, $P = 0.817$) reduction of 10.9%.

Including the "new" survey regions, our 2006-2007 estimate extrapolated from randomly-selected blocks is 9,187 ± 2,346 pairs (Table 4). Our "best estimate" for the same comprehensive area is a very similar 9,298 pairs (Table 4).

LAND OWNERSHIP AND HABITATS.

Similar to the findings reported by DeSante et al. (2007), we found that the vast majority of California's breeding Burrowing Owls occur on private lands (Table 5). Small numbers were also found on lands managed by four federal agencies, California state government, and local municipalities (Table 5).

The Burrowing Owls detected during our survey occupied a wide range of habitats, including natural grasslands, agricultural lands, and other human-modified areas (Table 6). Nearly one third of breeding sites were located on the banks of irrigation canals or other concrete or earthen water conveyance structures (Table 6).

DeSante et al. (2007) reported a strong association between Burrowing Owl breeding sites and the presence of ground squirrels. Our results corroborated this finding, but also revealed that association to be far weaker for owls nesting along irrigation canals and other water conveyance structures (Table 6). This weaker association presumably stems from owls not having to depend on ground squirrels for burrow excavation along canal banks, where earthen banks may be particularly easy to excavate, and concrete-lined banks often provide attractive nesting spaces between the concrete lining and the underlying soil.

OWL PERSISTENCE ON SURVEY BLOCKS OCCUPIED DURING THE 1991-1993 SURVEY

Considering blocks surveyed during both 1991-1993 and 2006-2007, in which owls were detected during the first (1991-1993) survey ($N = 149$), we found that abundance significantly declined (mean difference = -2.68 ± 0.50; $t = -5.37$; df = 148; $P < 0.0001$). The probability of detecting

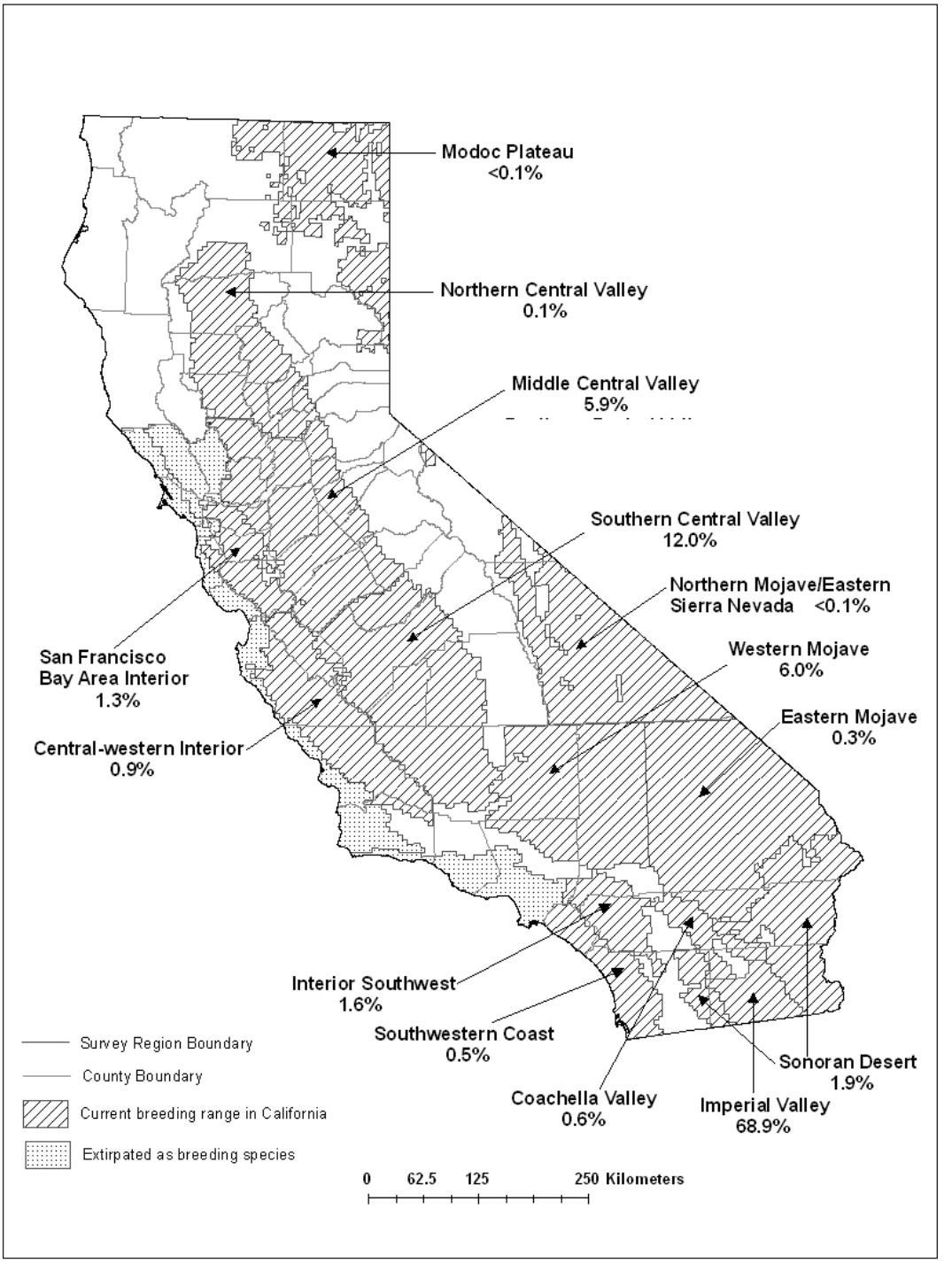

FIGURE 13. Current and former breeding range of Burrowing Owl in California, and percent of the 2006-2007 statewide breeding population estimated to occur in each region based on "best' estimates" (see Methods for explanation of "best" estimates) during the 2006-2007 survey.

TABLE 5. Number and percent of owl pairs detected during the 2006 and 2007 statewide Burrowing Owl survey, classified by land ownership or jurisdiction.

Land ownership or jurisdiction	Number of Burrowing Owl pairs detected: Randomly-selected blocks only	Number of Burrowing Owl pairs detected: Randomly-selected blocks and historic breeding blocks
Private	415 (96.7%)	1,592 (90.6%)
Federal		
Bureau of Land Management	2 (0.5%)	18 (1.0%)
Department of Defense	12 (2.7%)	50 (2.8%)
NASA	0	11 (0.6%)
National Wildlife Refuge System	0	38 (2.2%)
Local government	0	26 (1.5%)
State government	0	22 (1.3%)
Tribal	0	1 (0.1%)
Total	429	1,758

TABLE 6. Primary habitats indicated by field observers at sites where Burrowing Owl pairs were found, and prevalence of ground squirrels at those sites.

Primary habitat	No. of breeding sites[a]	No. of sites where ground squirrel presence was assessed	Percentage of assessed sites with ground squirrels present
Irrigation canal[b]	383	285	19
Natural grassland	211	211	92
Idle or fallow field	121	103	76
Field crop	114	10	60
Pasture	100	100	87
Brushland	75	75	67
Airport	45	45	91
Golf course	30	30	100
Levee	27	26	92
Railroad	26	26	85
Grain or hayfield	25	21	57
Row crop	14	6	43
Other	116	107	48
Total	1,287	1,045	64

[a]In many cases breeding sites encompassed multiple Burrowing Owl pairs.
[b]Here the term "irrigation canal" is used broadly to indicate any man-made concrete or earthen water conveyance structure.

owls on those blocks during the 2006-2007 survey increased as a function of the number of owls detected during the 1991-1993 survey (Fig. 14; $\chi^2_1 = 12.41$; $P = 0.0004$). For example, the predicted probability of detecting owls during the 2006-2007 survey in blocks where just one pair was detected during the 1991-1993 survey was about 0.36, compared to 0.93 in blocks where 25 pairs of owls were detected during the 1991-1993 survey.

DISCUSSION

Our survey method likely contains some systematic sources of error. As DeSante et al. (2007) pointed out, the inability of observers to

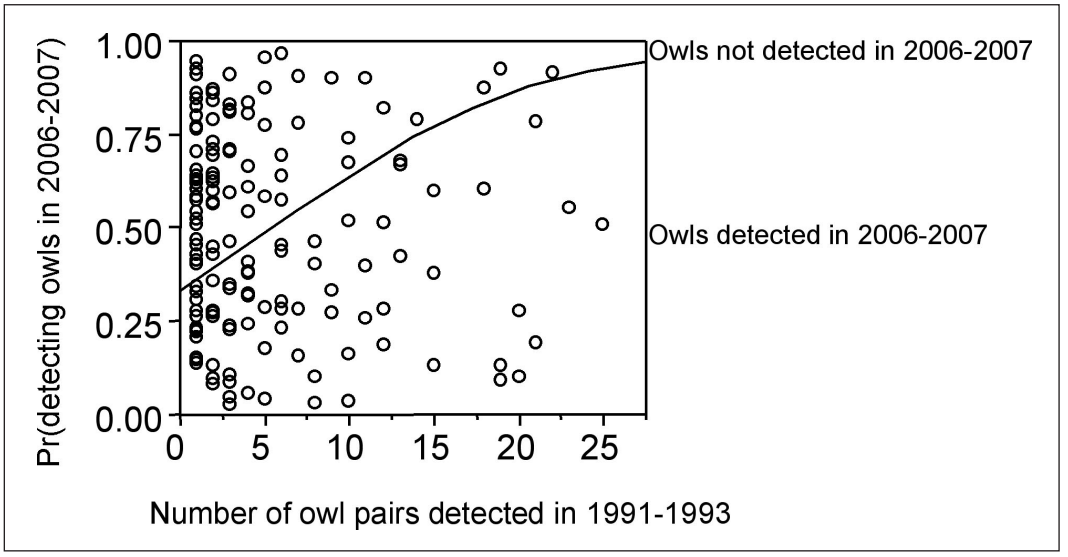

FIGURE 14. Probability of detecting owls during the 2006-2007 survey in blocks where owls were detected in 1991-1993 as a function of the number of owl pairs detected on the block in 1991-1993. The predicted probability of detection in 2006-2007 is shown by the curve. Data points below the curve are blocks on which owls were detected during both surveys; data points above the curve represent blocks where owls were detected in 1991-1993 but not detected in 2006-2007. Data points are plotted at their 1991-1993 owl pair (x-axis) values and randomly jittered in the probability (y-axis) space (below or above the curve, depending on whether owls were present in 2006-2007) to show the distribution of the data.

reliably detect all owls in sampled areas (Conway and Simon 2003, Conway et al. 2008), particularly in areas with limited or no road access may tend to bias our estimates low. Additionally, observers generally assumed that whenever they detected a single adult Burrowing Owl, it represented a breeding pair. To the extent that unmated adult birds may have been detected, this could result in an upward bias in our estimate of breeding pairs. Another potentially confounding factor was that surveyors were unable to gain access to some military installations and private landholdings; if such areas were more or less likely to be occupied by owls than other areas, bias in one direction or the other could have been introduced into our estimates. Finally, our survey methodology incorporated no means for assessing detection probability, which in some environments (such as desert areas with very low road density) may have been quite low. Perhaps of even greater concern than detection probability being low is that it could have varied substantially across survey blocks or survey regions with different physiographic characteristics.

Nevertheless, we believe the sheer volume of data collected counterbalances some of the methodological limitations described above, and ensures that the broader patterns in distribution and abundance are meaningful. Additionally, because our methods adhered to those established by DeSante et al. (2007), any biases affecting our results likely affected the 1991-1993 study, too, so that comparisons between the two surveys are appropriate. Finally, our survey documented the exact locations of 1,758 Burrowing Owl pairs (18.9% of the estimated total) across California, information that should be of great use for ongoing and future conservation efforts.

The generally large variances associated with our regional and statewide population estimates extrapolated from randomly-selected blocks indicate that our statistical power to detect changes in abundance was rather weak. Indeed, the Northern Central Valley was the only region for which our 2006-2007 population estimate differed significantly from the 1991-1993 estimate of DeSante et al. (2007). Moreover, many of

our regional "best estimates" were not obtained by extrapolating data from the randomly-selected blocks, but rather by simply counting all of the owl pairs that could be found in either randomly-selected or historical breeding blocks. We had no means for assessing statistical significance of such estimates from the corresponding 1991-1993 "best estimates", many of which were generated in the same manner. Nevertheless, inspection of our results, and qualitative comparisons with results from the 1991-1993 survey, still yield some important conclusions.

The major patterns in Burrowing Owl distribution and abundance across California described by DeSante et al. (2007) have not changed dramatically since 1991-1993, when the species was already extirpated or nearly extirpated from the San Francisco Bay Area Coast, Central-western Coast, and Southwestern Coast regions. The Imperial Valley still accounts for slightly more than two-thirds of the estimated statewide population, and the Southern Central Valley remains the second largest Burrowing Owl population center. Populations in other regions of the state that were surveyed in 1991-1933 all remain much smaller than those in the two most heavily populated regions.

While not statistically significant, we observed apparent declines in two urban areas: San Francisco Bay Area Interior Region and the Bakersfield area in the Southern Central Valley region. The San Francisco Bay Area Interior region's breeding owl population is both small and well-known by local birders and researchers, making it very likely that the "best estimates" from both the 1991-1993 and 2006-2007 surveys reflect very nearly all the owl pairs actually present. Consequently, the apparent loss of 27.9% of the population, from 165 to 119 pairs since the early 1990s survey, is somewhat alarming. This loss includes the last known pairs of owls in both Sonoma and San Mateo counties, and suggests that Burrowing Owls have now been extirpated as a breeding species in the entire San Francisco Bay Area, except for Alameda and Santa Clara counties, where populations have also declined. It should be noted that Burrowing Owl populations can fluctuate annually, so our lower count of owls in the region does not necessarily indicate a deterministic decline. However, the increasingly restricted distribution of the species throughout the region would seem to indicate that such a trend is real.

In the greater Bakersfield area, heavy losses (nine blocks lost a total of 96 pairs) appear to be associated with recent land conversion from agriculture to urban, though a finer resolution spatial assessment would be helpful to determine whether such land conversion really has driven the losses. In any case, it seems that like the San Francisco Bay Area, the greater Bakersfield area is in danger of losing most if not all of its once substantial Burrowing Owl population. This is particularly unfortunate because the species exhibits a remarkable degree of tolerance for human alteration of natural habitats (Klute et al. 2003, Chipman et al. 2008), often nesting within landfills, golf courses, airports, and vacant lots within urban areas (Haug et al. 1993, Trulio 1997). This tolerance of humans and their activities would seem to provide ample opportunity for successful conservation efforts, even in the context of urban areas with growing human populations. One result, showing that the likelihood of Burrowing Owls persisting through 2006-2007 on survey blocks where they were present in 1991-1993 was strongly and positively related to the number of owls that were present on the blocks in 1991-1993, underscores the precariousness of dwindling urban-area populations, and the need for rapid action to prevent local extirpation.

In contrast to areas where we noted declines, we also noted areas where Burrowing Owls may have increased since the 1991-1993 survey: the Central-Western Interior region and the Coachella Valley. However, we surveyed a much greater number of upland blocks in contrast to the earlier survey in the Central-Western Interior region, so the apparent increase could be an artifact due to increased surveys effort. In contrast, the apparent increase (from zero to 53 owl pairs) in the Coachella Valley seems more likely to indicate a real increase in owl presence, especially because we found multiple Burrowing Owl pairs on four blocks in the region that were also surveyed in the early 1990s, but yielded no detections at that time. Interestingly, none of the pairs we found in Coachella Valley appeared to be associated with agriculture or water conveyance structures;

rather they occupied a variety of relatively arid habitats including brushland, desert scrub, and natural grasslands, and appear to be clustered on the outskirts of urban development.

Large confidence intervals make comparing our statewide population estimate with that of DeSante et al. (2007) during 1991-1993 difficult, especially since the difference in the estimates is relatively small. Three quarters of owl pairs in our aggregated population estimate reside in the densely occupied Imperial Valley, where the standard error associated with our regional estimate is well over 2,000 pairs. Thus, the lack of precision in this single regional estimate could easily mask a real statewide decline, or for that matter, potentially even obscure a statewide increase. Future survey efforts could perhaps minimize the problem of low statistical power by focusing monitoring efforts on smaller areas selected for high owl population density or other factors, and sustaining those efforts for multiple successive breeding seasons.

Our survey of the "new" survey regions covering the Modoc Plateau/Great Basin, Mojave Desert, and Sonoran Deserts represents the first systematic survey of Burrowing Owls across vast portions of California. We found Burrowing Owls to be distributed heterogeneously among these regions, with few or no owls in the Modoc Plateau/Great Basin, Northern Mojave/Eastern Sierra Nevada, Eastern Mojave, or Sonoran Desert regions (excluding the Palo Verde Valley). However, we found much larger aggregations of burrowing Owls in the Western Mojave region, and in one small area of the Sonoran Desert—the Palo Verde Valley.

CONSERVATION IMPLICATIONS

A comprehensive conservation strategy for Burrowing Owl in California is under development by California Department of Fish and Game and its partners (Burkett and Johnson, 2008). Here we provide a few conservation-related conclusions and recommendations that stem directly from our results:

1) Despite the apparent robustness of the population in the Imperial Valley, smaller populations elsewhere in the state, particularly in and near urban areas, appear to have continued to decline since the 1991-1993 survey.

2) The vast majority of the state's breeding Burrowing Owls continue to nest on private lands; any meaningful conservation efforts must therefore engage private stakeholders.

3) Across much of California, Burrowing Owl nesting remains closely associated with the presence of ground squirrels, another factor that must be considered in developing successful conservation measures.

4) In a few key areas, particularly the Imperial Valley and the Palo Verde Valley, Burrowing Owls are not closely associated with ground squirrels, and instead rely heavily on the banks of concrete and earthen water conveyance structures for nesting sites. Comprehensive conservation planning for Burrowing Owl in California must take into consideration the importance of these artificial structures.

5) Although Burrowing Owl detections were scarce across most of the land area of the newly surveyed Modoc Plateau/Great Basin and southern California desert regions, substantial populations persist in the Sonoran Desert (Palo Verde Valley) and the western Mojave Desert regions (particularly in and around the Antelope, Apple, and Lucerne valleys). We estimate the western Mojave Desert region to contain ~6% of California's breeding Burrowing Owls, superseded in numerical importance to the statewide population only by the Imperial Valley and the Southern Central Valley regions. Successful conservation planning for this species must address the particular needs of these substantial desert populations (Wilkerson and Siegel, *in press*).

6) A statewide conservation strategy will likely need to incorporate a statewide monitoring program to assess the effectiveness of conservation measures. Our study demonstrates the potential value of citizen-science participation in single-species studies, particularly of raptors or other highly charismatic species like Burrowing Owls that are relatively easy to find and identify. While many of our volunteer observers were highly skilled birders, and in some cases, even wildlife professionals, others had little or no birding experience. With a fairly modest investment of time and money for recruiting, training, and supporting volunteer surveyors, we were able to extend our survey across a vast area. Engaging citizen-scientists in monitoring could reduce the cost and extend the scope of any owl monitoring project, and may also yield less tangible benefits — participants in

citizen science monitoring programs can reap an increased awareness and appreciation of study organisms and their habitats, which may then translate into tangible actions on their behalf (Evans et al. 2005).

ACKNOWLEDGMENTS

This project was made possible by funding from the National Fish and Wildlife Foundation, California Department of Fish and Game, Pacific Gas and Electric Company, and an anonymous donor. We thank Esther Burkett at California Department of Fish and Game for supporting this project in numerous ways, David DeSante at The Institute for Bird Populations for sharing his knowledge and providing survey advice, and Jim Saracco at The Institute for Bird Populations for statistical advice. Sue Townsend and David Ainley provided helpful comments on the manuscript. We thank the ESRI Conservation Program for software support.

We thank the following individuals for serving as volunteer coordinators for their counties or areas in 2006, in 2007, or in both years: Marie Barrett, Rich Cimino, Chris Conard, Jeff Davis, Jimm Edgar, Mike Fisher, Dawn Garcia, Dan Guthrie, Darrell Hutchinson, Cheryl Johnson, Robin Leong, Krista Maney, Jessica Martini, Catherine Portman, Tom Ryan, Debra Shearwater, Ginny Short, Ian Taylor, Ruth Troetschler, Dave Wagner, and Carie Wingert. Other individuals who did not serve as coordinators but nevertheless contributed substantial local information and/or logistic help included Roger Higson (Palo Verde Valley) and Ryan Young (Antelope Valley).

We are especially grateful to the following volunteers for participating in the survey of one or more survey blocks: Jennifer Albright, Chris Alderete, Diana Alleman, Lisa Allen, Russell Almaraz, Jerry W. Ambrose, Mary Ann Ambrose, Sundeep Amin, Chloe Anderson, Simon Avery, Joellyn Avery, Patricia Bacchetti, Jason Bachiero, Valerie Baldwin, Jack Barclay, Marie Barrett, Margaret Barson, Peggy Bartels, Candice Basham, Jeff Beauchamp, David Bell, Joyce Bender, Judy Bendix, Debbie Benham, Vern Benhart, Nicola Bennert, Josh Bennett, Murray Berner, Linda Bernhart, Milton Blatt, Diane Bodwin, Anita K. Booth, Brian Botham, Dawn Bradley, Steve Brady, Tricia Bratcher, Theresa Brennan, Craig Breon, Beverly Brock, Charles R. Brown, Philip Brown, Debbi Brusco, Julie Bryson, Virginia Buchholz, Maureen Buffington Santo, Cheri Buskirk, Dotty Calabrese, Karlene Campo, David Carr, Chuck Carroll, Randi Cassellius, Joyce Chang, Tony Chapelle, Sophie Chiang, David Chilton, Kirsten Christopherson, Jeff Church, Rich Cimino, Mareyn Clements, Richard Clements, Neil Clipperton, Wendy Cole, Barbara Coley, Roger Coley, James M. Collier, Judith A. Collier, Chris Conard, David Cook, Daniel S. Cooper, Curt Cotner, Erica Craven, Anne Crealock, Lori Cuesta, Cindy Curtis, Ken Curtis, Kirsten Dahl, Virginia L. Dallas-Dull, Larry Davidson, Jeff N. Davis, Karen DeMello, Susan Dieterich, Joan Dodson, Jim Dodson, Jed Douglas, Peter Drumer, Doug Drynan, Jim Dunn, Natasha Dvorak, R. Eckland, Jimm Edgar, Arthur L. Edwards, Linda Edwards, Lorna Elness, Mark Elness, Madi Elsea, Kevin Enus-Rempel, Laura Erickson, Janeann Erickson, Jake Estis, Mary Fajekers, Jonathan Feenstra, Stacey Feigekonwiesr, Hank Feilen, Jane Fielder, Megan Fisher, Mike Fisher, Tim Fitzer, Kasey Foley, Joel Forty, Bennie Fouch, Scott Frazer, Linda Freeman, Mary Freeman, Nick Freeman, Parker Fritch, Lillian Fuji, Harold Fukuma, Barry Furst, Dawn Garcia, Melisa Garcia, Maureen Geiger, Harriet Gerson, Brian Gibson, Neil Gilbert, Steven Glover, Dave Goodward, Debbie Green, John F. Green, Richard Greene, Linda Greene, Christina Greutink, Dan Guthrie, Samantha Hafter, Portia Halbert, Catherine Halley, Devon Hammond, Lindsay Harman, Kristey Harrington, Carmen Hashagen, Ken Hashagen, Cole Hawkins, Priscilla Hawkins, Steve Hayashi, Ursula Heffernon, Lynn Hemink, J. Herman, Philip Higgins, Jon Hilbert, Carolyn Hinshaw, Allan Hollander, Lindsay Holt, Amber Holt, Kathryn Hood, Scott Huber, Liam Huber, Sherry Hudson, Bobby Huss, Darrell Hutchinson, Meighan Jackson, Sue James, Tim Jenkins, Phil Johnson, Vernon Johnson, Dave Johnston, Jennifer Jones, Douglas Joo, Linda Jordan, Ginny Kaminski, Jerry Kaminski, Martin Karsch, Lola Kashyap, Maral Kasparian, Guy Kay, David Keeling, Elena Keeling, Mary Keitelman, Lazan Keitelman, Ruth Kennedy, Stephen King, Judy Klink, Oliver Klink, Joanna Koob, Eva Kristofik, Nathan Krumm, Tim LaFlame, Kimya Lambert, Aleatha W. Landry, Steve Laymon, Cathie LaZier, Rod Lee, Sara Lee, Lora Leerskov, Robin

Leong, John Lewis, Phyllis Lindley, Inna Litvin, Ivette Loredo, Kent D. Lou, Calvin D. Lou, Raymond Lukens, John Luther, Bill Lydecker, Greta Lydecker, Sarah Lydecker, Betty MacDonald, John MacDonald, Chris Macintosh, Jeanne Macneil, Shelly Magier, Ernie Maier, Colleen Martin, Cheryl McCloskey, Kally McCormick, Walter J. McInnis, Gregory Meissner, Mary Beth Metcalf, Susanne Methvin, Jay Milee, Ashley Miller, Mel Miller, Karen Mitchell, Richard Montijo, Alan Moore, Kris Moore, Richard Moore, Nancy Mori, Suzanne Morron, Gerald Mugele, Jerre Murphy, Gordon Murphy, Sue Murphy, Ted Murphy, Jean Myers, George Nash, Kelley Nelson, Nancy Nelson, Wallace Neville, Renee New, Maggie Nunes, Michelle Ocken, D. O'Keefe, Rodney Olsen, Jennifer O'Neal, Regina Orr, William Orr, Ed Pandolfino, Kay Partelow, Warren Patten, Jennifer Patten, Janna Pauser, Mark Paxton, Fraser Pembeiton, Barbara Pendergrass, David Perrin, Sarah Perrin, Marilynn Perry, Dawn Peterka, Paula Peterson, Randall Peterson, Susan Peterson, Carole Petrash, Shawn Petrash, David G. Philled, Sarah Pitzer, Ken Poerner, Kathy Porter, Marian Porter, Catherine Portman, Bob Power, Ted Raczek, Corina Rahmig, Troy Rahmig, Siddharthan Ramachandramurthi, Art Ramirez, George Rawley, Tricia Reed, Crispin Rendon, Virginia Rhodas, Michael Richard, Bob Richmond, Mike Richter, Matt Ritchie, Michael Robertson, Caroline Rodgers, Tobias Rohmer, Ann Romer, Sarah Ross, Patricia Rouzer, Jim Rowoth, Suzanne Ruckle, Tim Ruckle Jr., Tim Ruckle Sr., Ruth Rudesill, Michael Ruffino, Heather Ryan, Jeff Ryan, Thomas Ryan, Jennifer Rycenga, Donna Sadowy, Nancy Sage, John Santo, Fran Scarlett, Diana Scheel, Lexie Scheel, John Schick, Paul Schorr, Nancy Schorr, Mauricio Schrader, Steve Schwartz, Katie Schwartz, Steve Scott, Jeff Seav, Norman Self, Tracey Sharp, Kathy Sharum, Jackson Shedd, Kathy Shick, Robert Shields, Carolyn Short, Ginny Short, Rodney Siegel, Mike Skram, Dale M. Smith, Greg Smith, Michael W. Smith, Curtis Snyder, Tate Snyder, Susan Stanton, Jim Steinert, Sarah Stier, Steve Stocking, Mike Stockton, Brad Stovall, Bruce Strang, Nancy Strang, Linda Swanson, Dan Tankersley, Ian Taylor, Lynn R. Thomas, Jennifer Thompson, Christine Tischen, Christine Tisher, Gene Troetschler, Ruth Troetschler, Jeff Trow, Lisa Twiford, Linda Vallee, Ann Verdi, Chuck Verturri, Jamie Visinoni, Jim Waddell, Lisa Wadley, Dave Wagner, Annette Waite, Lucy Waite, Dee Warenycia, Dean Webb, Daniela Wersin, Kimberly West, Liz West, V. Wheeler, Jonathan Widdicombe, Bruce Wilcox, Bob Wilkerson, Anne Williams, Dan Williams, James Williams, M. Williams, Pam Williams, Bruce Williford, Michael Wilson, Carrie Wingert, Gary Woods, Lois Wren, Rick Wulbern, Faith Yamane, Chad Young, Ryan Young, and Bill Zachman.

We thank the following individuals for surveying numerous blocks as part of IBP's full-time field crew: Mary Coolidge (2007 crew leader), Ilma Dancourt, Corey Kaleshnik, Amanda LeClerc, Timothy McClung, Alison Mohoric, Becky Parsons, Matthew Simes, Chantal Villeneuve, Zach Wallace, and Aaron Works. This is Contribution No. 392 of The Institute for Bird Populations.

LITERATURE CITED

BAIRD, S. F. 1870. Ornithology. Volume I. Land birds. Geological Survey of California. Edited by S. F. Baird from the manuscript and notes of J. G. Cooper.

BARCLAY, J. H. 2007. Burrowing Owl management at Mineta San Jose International Airport, p. 146-154. *In* J. H. Barclay, K. W. Hunting, J. L. Lincer, J. Linthicum, and T. A. Roberts [Eds.], Proceedings of the California Burrowing Owl Symposium, November 2003. Bird Populations Monographs No. 1. The Institute for Bird Populations and Albion Environmental, Inc., Point Reyes Station, CA.

BARCLAY , J. H., AND L. HARMAN. 2007. 2007 nesting Burrowing Owl census: Souza and Vasco Caves parcels. Albion Environmental, Inc., Santa Cruz, CA.

BURKETT, E. E., AND B. S. JOHNSON. 2007. Development of a conservation strategy for Burrowing Owls in California, p. 165-168. *In* J. H. Barclay, K. W. Hunting, J. L. Lincer, J. Linthicum, and T. A. Roberts [Eds.], Proceedings of the California Burrowing Owl Symposium, November 2003. Bird Populations Monographs No. 1. The Institute for Bird Populations and Albion Environmental, Inc., Point Reyes Station, CA.

CALIFORNIA DEPARTMENT OF FISH AND GAME. 2006. California Natural Diversity Database. Updated 2006. California Department of Fish and Game, Biogeographic Data Branch, Sacramento.

CALIFORNIA DEPARTMENT OF FORESTRY AND FIRE

PROTECTION. 2002. Multi-source Land Cover Data (v02_2). Forest and Range Assessment Program. http://frap.fire.ca.gov/data/frapgisdata/download.asp?rec=fveg02_2

CALIFORNIA GAP ANALYSIS PROJECT. 1998. Gap analysis of mainland California: an interactive atlas of terrestrial biodiversity and land management. University of California, Santa Barbara.

CHIPMAN, E. D., N. E. MCINTYRE, R. E. STRAUSS, M. C. WALLACE, J. D. RAY, AND C. W. BOAL. 2008. Effects of human land use on western burrowing owl foraging and activity budgets. Journal of Raptor Research 42:87-98.

CONWAY, C. J., AND J. SIMON. 2003. Comparison of detection probability associated with Burrowing Owl survey methods. Journal of Wildlife Management 67:501-511.

CONWAY, C. J., V. GARCIA, M. D. SMITH, AND K. HUGHES. 2008. Factors affecting detection of Burrowing Owl nests during standardized surveys. Journal of Wildlife Management 72:688-696.

CULL, R. L., AND F. HALL. 2007. Status of Burrowing Owls in northeastern California, p. 42-51. In J. H. Barclay, K. W. Hunting, J. L. Lincer, J. Linthicum, and T. A. Roberts [Eds.], Proceedings of the California Burrowing Owl Symposium, November 2003. Bird Populations Monographs No. 1. The Institute for Bird Populations and Albion Environmental, Inc., Point Reyes Station, CA.

CUOLOMBE, H. N. 1971. Behavior and population ecology of the burrowing owl, *Speotyto canicularia*, in the Imperial Valley of California. Condor 73:162-176.

DAWSON, W. L. 1923. The birds of California. Volume Two. South Moulton Company, San Diego.

DESANTE, D. F., E. D. RUHLEN, AND D. K. ROSENBERG. 2004. Density and abundance of Burrowing Owls in the agricultural matrix of the Imperial Valley, California. Studies in Avian Biology 27:116-119.

DESANTE, D. F., E. D. RUHLEN, AND R. SCALF. 2007. The distribution and relative abundance of Burrowing Owls in California during 1991-1993: evidence for a declining population and thoughts on its conservation, p. 1-41. *In* J. H. Barclay, K. W. Hunting, J. L. Lincer, J. Linthicum, and T. A. Roberts [Eds.], Proceedings of the California Burrowing Owl Symposium, November 2003. Bird Populations Monographs No. 1. The Institute for Bird Populations and Albion Environmental, Inc., Point Reyes Station, CA.

EVANS, C., E. ABRAMS, R. REITSMA, K. ROUX, L. SALMONSEN, AND P. P. MARRA. 2005. The Neighborhood Nestwatch Program: participant outcomes of a citizen-science ecological research project. Conservation Biology 19:589-594.

GERVAIS, J. A. 2002. Evaluating space use and pesticide exposure risk for burrowing owls in an agricultural environment. Ph.D. dissertation, Oregon State University, Corvallis.

GERVAIS, J. A., AND R. G. ANTHONY. 2003. Chronic organochlorine contaminants, environmental variability, and the demographics of a burrowing owl population. Ecological Applications 13:1250-1262.

GERVAIS, J. A., D. K. ROSENBERG, AND L. A. COMRACK. 2008. Burrowing Owl (*Athene canicularia*). *In* W. D. Shuford and T. Gardali [Eds.], California Bird Species of Special Concern: a ranked assessment of species, subspecies, and distinct populations of birds of immediate conservation concern in California. Studies of Western Birds 1. Western Field Ornithologists, Camarillo, California, and California Department of Fish and Game, Sacramento.

GRINNELL, J. 1915. A distributional list of the birds of California. Pacific Coast Avifauna Number 11. Cooper Ornithological Club.

GRINNELL, J., AND A. H. MILLER. 1944. The distribution of the birds of California. Pacific Coast Avifauna, no. 27. Cooper Ornithological Club, Berkeley, CA.

HAUG, E. A., B. A. MILLSAP, AND M. S. MARTELL. 1993. Burrowing Owl (*Athene cunicularia*). *In* A. Poole [Ed.], The Birds of North America Online. Cornell Lab of Ornithology, Ithaca. Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/species/061

HICKMAN, J. C. [Eds.]. 1993. The Jepson manual: higher plants of California. University of California Press, Berkeley and Los Angeles.

HOLROYD, G. L., R. RRODRÍGUEZ-ESTRELLA, AND S. R. SHEFFIELD. 2001. Conservation of the Burrowing Owl in western North America: issues, challenges, and recommendations. Journal of Raptor Research 35:399-407.

JAMES, P. C., AND G. A. FOX. 1987. Effects of some insecticides on productivity of Burrowing Owls. Blue Jay 45:65-71.

JAMES, P. C., AND T. J. ETHIER. 1989. Trends in the winter distribution and abundance of burrowing owls in North America. American Birds 43:1224-1225.

KEELER, C. A. 1891. Geographical distribution of land birds in California. IV. The Island Fauna. Volume I.

KIDD, J. W., P. H. BLOOM, C. W. BARROWS, AND C. T. COLLINS. 2007. Status of Burrowing Owls in southwestern California, p. 76-89. *In* J. H. Barclay, K. W. Hunting, J. L. Lincer, J. Linthicum, and T. A. Roberts [Eds.], Proceedings of the California Burrowing Owl Symposium, November 2003. Bird Populations Monographs No. 1. The Institute for Bird Populations and Albion Environmental, Inc., Point Reyes Station, CA.

KLUTE, D. S., L. W. AYERS, M. T. GREEN, W. H. HOWE, S. L. JONES, J. A. SHAFFER, S. R. SHEFFIELD, AND T. S.

ZIMMERMAN. 2003. Status assessment and conservation plan for the Western Burrowing Owl in the United States. U.S. Department of Interior, Fish and Wildlife Service, Biological Technical Publication FWS/BTP-R6001-2003, Washington, D.C.

LINCER, J. L. AND P. H. BLOOM. 2007. The status of the Burrowing Owl in San Diego County, California, p. 90-102. *In* J. H. Barclay, K. W. Hunting, J. L. Lincer, J. Linthicum, and T. A. Roberts [Eds.], Proceedings of the California Burrowing Owl Symposium, November 2003. Bird Populations Monographs No. 1. The Institute for Bird Populations and Albion Environmental, Inc., Point Reyes Station, CA.

MULTI-RESOLUTION LAND CHARACTERISTICS CONSORTIUM. 2001. National Land Cover Database (NLCD 2001). http://www.mrlc.gov/nlcd.php

REMSEN, J. V., JR. 1978. Bird species of special concern in California. Prepared for the California Department of Fish and Game.

RONAN, N. A. 2002. Habitat selection, reproductive success, and site fidelity of burrowing owls in a grassland ecosystem. M.S. thesis, Oregon State University, Corvallis.

ROSENBERG, D. K. AND K. L. HALEY. 2004. The ecology of burrowing owls in the agro-ecosystem of the Imperial Valley, California. Studies in Avian Biology 27:120-135.

SAUER, J. R., J. E. HINES, AND J. FALLON. 2008. The North American Breeding Bird Survey, Results and Analysis 1966 - 2007. Version 5.15.2008. USGS Patuxent Wildlife Research Center, Laurel, MD.

SHEFFIELD, S. R. 1997a. Current status, distribution, and conservation of the Burrowing Owl in Midwestern and western North America. p. 399-408. *In* J. R. Duncan, D. H. Johnson, and T. H. Nichols [Eds.], Biology and conservation of owls of the northern hemisphere: 2nd international symposium. USDA Gen. Tech. Rep. NC-190, St. Paul, Minnesota.

SHEFFIELD, S. R. 1997b. Owls as biomonitors of environmental health hazards, p. 383-398. *In* J. R. Duncan, D. H. Johnson, and T. H. Nicholls [Eds.], Biology and conservation of owls in the northern hemisphere: 2nd international symposium. USDA Gen. Tech. Rep. NC-190, St. Paul, Minnesota.

SHUFORD, W. D., AND T. GARDALI [Eds.]. 2008. California bird species of special concern: a ranked assessment of species, subspecies, and distinct populations of birds of immediate conservation concern in California. Studies of Western Birds 1. Western Field Ornithologists, Camarillo, California, and California Department of Fish and Game, Sacramento.

THOMSEN, L. 1971. Behavior and ecology of Burrowing Owls on the Oakland Municipal Airport. Condor 73:177-192.

TOWNSEND, S. E. AND C. LENIHAN. 2007. Burrowing Owl status in the Greater San Francisco Bay Area, p. 60-69. *In* J. H. Barclay, K. W. Hunting, J. L. Lincer, J. Linthicum, and T. A. Roberts [Eds.], Proceedings of the California Burrowing Owl Symposium, November 2003. Bird Populations Monographs No. 1. The Institute for Bird Populations and Albion Environmental, Inc., Point Reyes Station, CA.

TRULIO, L. A. 1997. Strategies for protecting western burrowing owls (*Speotyto cunicularia hypugaea*) from human activities, p. 461-465. *In* J. R. Duncan, D. H. Johnson, and T. H. Nicholls (eds.). Biology and conservation of owls in the northern hemisphere. USDA Forest Service General Technical Report NC-190. St. Paul, Minnesota.

TRULIO, L. A. AND D. A. CHROMCZAK. 2007. Burrowing Owl nesting success at urban and parkland sites in northern California, p. 115-122. In J. H. Barclay, K. W. Hunting, J. L. Lincer, J. Linthicum, and T. A. Roberts [Eds.], Proceedings of the California Burrowing Owl Symposium, November 2003. Bird Populations Monographs No. 1. The Institute for Bird Populations and Albion Environmental, Inc., Point Reyes Station, CA.

WEDGWOOD, J. A. 1978. The status of the burrowing owl in Canada. Committee on the Status of Endangered Wildlife in Canada. Can. Wildl. Serv., Ottawa, ON, Canada.

WELLICOME, T. I. AND G. L. HOLROYD. 2001. The second international burrowing owl symposium: background and context. Raptor Research Report 35:269-273.

WILKERSON, R. L., AND R. B. SIEGEL. *In review*. Burrowing Owl distribution and abundance in southeastern California. The Southwestern Naturalist.

ZAR, J. H. 1984. Biostatistical analysis. Prentice Hall, Englewood Cliffs, NJ.

ZARN, M. 1974. Burrowing Owl (*Speotyto cunicularia hypugaea*). Habitat management series for unique or endangered species, U.S. Bureau of Land Management. Tech. Note 242, Denver, CO.

SPRING 2008 NEWSLETTER

FINAL SURVEY RESULTS ARE IN!

It required literally thousands of volunteer hours, but you did it! During the 2006 and 2007 breeding seasons, 396 volunteer surveyors contributed their time and effort to **The Institute for Bird Populations**' California Burrowing Owl survey, bringing the total number of 5km x 5km survey blocks visited to 860! We at IBP are very pleased with these results, and extend a heartfelt **THANK YOU** to everyone who participated.

The table at the right provides some summary results. As expected, the highest concentrations of Burrowing Owls occurred in the Imperial Valley and Southern Central Valley regions; perhaps more surprising was the relatively large number of owls in the Western Mojave region, particularly around Antelope Valley. More disappointing were the results from the Bay Area Interior region (112 pairs counted, down substantially from our count in the early 1990s) and the Modoc Plateau/Great Basin region, where we were unable to find *any* Burrowing Owls. Note that the numbers presented here are the actual numbers of owl pairs counted in each region, pooling results across both random and historical 'owl' blocks. We are now using statistical techniques to estimate regional population sizes based on these survey counts, and to compare the new regional and statewide estimates with results from our similar survey in the early 1990s.

Survey Region	No. of Blocks Surveyed (2006-2007)	Pairs of Burrowing Owls Detected
Bay Area Interior	89	112
Middle Central Valley	200	382
Northern Central Valley	48	10
Southern Central Valley	164	236
Central-western Interior	44	21
Southwestern Interior	68	150
Coachella Valley	20	49
Imperial Valley	15	521
Eastern Mojave	46	1
Western Mojave	67	94
Northern Mojave/ Eastern Sierra Nevada	38	1
Sonoran Desert	46	179
Modoc Plateau/ Great Basin	15	0
Total	**860**	**1,756**

Preliminary results suggest that Burrowing Owl distribution across the state may have contracted slightly since the early 1990s, particularly in the northern half of the state. Abundance appears to have declined slightly in many regions, though observed declines generally do not reach the threshold of statistical significance. Burrowing Owl numbers in a couple of metropolitan areas, particularly the San Francisco Bay Area and Bakersfield, have dropped substantially since the early 1990s. However, one bright spot is the Coachella Valley, where we detected no Burrowing Owls in the early 1990s, but where 49 pairs were observed during 2006-2007—many on the same individual census blocks that were found not to have owls in the 1990s.

Photo by Dave Herr

Recent, current and future activities…

Since the 2007 field season, IBP Biologist Bob Wilkerson has presented our preliminary results at two statewide meetings: a joint meeting of the California Burrowing Owl Consortium (CBOC) and California Partners in Flight in Davis, and another CBOC meeting in Brawley. More recently we have begun work on our Final Report to our funders (including the National Fish and Wildlife Foundation and the California Department of Fish and Game) as well as a manuscript for submission to a peer-reviewed scientific journal. We also intend to post detailed results on our website (www.birdpop.org).

Finally, many survey volunteers have asked about opportunities to participate in Burrowing Owl monitoring during 2008 and future years. We are grateful to everyone who has expressed interest. Although we think California's Burrowing Owls would be well-served by a long-term, volunteer-based monitoring program, we have not yet succeeded in securing funding to coordinate such an effort. Should funding become available in the future, we hope many of our 2006-2007 surveyors will heed the call to participate!

THANK YOU FOR YOUR TIME AND EFFORT!

The following individuals served as volunteer coordinators for their county or area in 2006, in 2007, or in both years: Marie Barrett, Rich Cimino, Chris Conard, Jeff Davis, Jimm Edgar, Mike Fisher, Dawn Garcia, Dan Guthrie, Darrell Hutchinson, Cheryl Johnson, Robin Leong, Krista Maney, Jessica Martini, Catherine Portman, Tom Ryan, Debra Shearwater, Ginny Short, Ian Taylor, Ruth Troetschler, Dave Wagner, and Carie Wingert.

The following individuals participated in censusing one or more survey blocks during either or both of the two survey years: Jennifer Albright, Chris Alderete, Diana Alleman, Lisa Allen, Russell Almaraz, Jerry W. Ambrose, Mary Ann Ambrose, Sundeep Amin, Chloe Anderson, Simon Avery, Joellyn Avery, Patricia Bacchetti, Jason Bachiero, Valerie Baldwin, Jack Barclay, Marie Barrett, Margaret Barson, Peggy Bartels, Candice Basham, Jeff Beauchamp, David Bell, Joyce Bender, Judy Bendix, Debbie Benham, Vern Benhart, Nicola Bennert, Josh Bennett, Murray Berner, Linda Bernhart, Milton Blatt, Diane Bodwin, Anita K. Booth, Brian Botham, Dawn Bradley, Steve Brady, Tricia Bratcher, Theresa Brennan, Craig Breon, Beverly Brock, Charles R.

Brown, Philip Brown, Debbi Brusco, Julie Bryson, Virginia Buchholz, Maureen Buffington Santo, Cheri Buskirk, Dotty Calabrese, Karlene Campo, David Carr, David W. Carr, Chuck Carroll, Randi Cassellius, Joyce Chang, Tony Chapelle, Sophie Chiang, David Chilton, Kirsten Christopherson, Jeff Church, Rich Cimino, Mareyn Clements, Richard Clements, Neil Clipperton, Wendy Cole, Barbara Coley, Roger Coley, James M. Collier, Judith A Collier, Chris Conard, David Cook, Mary Coolidge, Daniel S. Cooper, Curt Cotner, Erica Craven, Anne Crealock, Lori Cuesta, Cindy Curtis, Ken Curtis, Kirsten Dahl, Virginia L. Dallas-Dull, Ilma Dancourt, Larry Davidson, Jeff N. Davis, Karen DeMello, Susan Dieterich, Joan Dodson, Jim Dodson, Jed Douglas, Peter Drumer, Doug Drynan, Jim Dunn, Natasha Dvorak, R. Eckland, Jimm Edgar, Arthur L. Edwards, Linda Edwards, Lorna Elness, Mark Elness, Madi Elsea, Kevin Enus-Rempel, Laura Erickson, Janeann Erickson, Jake Estis, Mary Fajekers, Jonathan Feenstra, Stacey Feigekonwiesr, Hank Feilen, Jane Fielder, Megan Fisher, Mike Fisher, Tim Fitzer, Kasey Foley, Joel Forty, Bennie Fouch, Scott Frazer, Linda Freeman, Mary Freeman, Nick Freeman, Parker Fritch, Lillian Fuji, Harold Fukuma, Barry Furst, Dawn Garcia, Melisa Garcia, Maureen Geiger, Harriet Gerson, Brian Gibson, Neil Gilbert, Steven Glover, Dave Goodward, David Goodwawrd, Debbie Green, John F. Green, Richard Greene, Linda Greene, Christina Greutink, Dan Guthrie, Samantha Hafter, Portia Halbert, Catherine Halley, Devon Hammond, Lindsay Harman, Kristey Harrington, Carmen Hashagen, Ken Hashagen, Cole Hawkins, Priscilla Hawkins, Steve Hayashi, Ursula Heffernon, Lynn Hemink, J. Herman, Philip Higgins, Jon Hilbert, Carolyn Hinshaw, Allan Hollander, Lindsay Holt, Amber Holt, Kathryn Hood, Scott Huber, Liam Huber, Sherry Hudson, Bobby Huss, Darrell Hutchinson, Meighan Jackson, Sue James, Tim Jenkins, Phil Johnson, Vernon Johnson, Dave Johnston, Jennifer Jones, Douglas Joo, Linda Jordan, Corey Kaleshnik, Ginny Kaminski, Jerry Kaminski, Martin Karsch, M. Karsch, Lola Kashyap, Maral Kasparian, Guy Kay, David Keeling, Elena Keeling, Mary Keitelman, Lazan Keitelman, Ruth Kennedy, Stephen King, Judy Klink, Oliver Klink, Joanna Koob, Eva Kristofik, Nathan Krumm, Tim LaFlame, Kimya Lambert, Aleatha W. Landry, Steve Laymon, Cathie LaZier, Amanda LeClerc, Rod Lee, Sara Lee, Lora Leerskov, Robin Leong, John Lewis, Phyllis Lindley, Inna Litvin, Ivette Loredo, Kent D. Lou, Calvin D. Lou, Raymond Lukens, John Luther, Bill Lydecker, Greta Lydecker, Sarah Lydecker, Betty MacDonald, John MacDonald, Chris Macintosh, Jeanne Macneil, Shelly Magier, Ernie Maier, Colleen Martin, Cheryl McCloskey, Tim McClung, Kally McCormick, Walter J. McInnis, Gregory Meissner, Mary Beth Metcalf, Susanne Methvin, Jay Milee, Ashley Miller, Mel Miller, Karen Mitchell, Allison Mohoric, Richard Montijo, Alan Moore, Kris Moore, Richard

···Burrowing Owl Survey Hall of Fame···

Who found the greatest number of Burrowing Owls on a single block in 2007?

Bruce Wilcox, with 52 pairs on block # 3650-645 in the Imperial Valley

···Burrowing Owl Survey Hall of Fame··· Top Ten Block Surveyors for 2007

Name	Blocks Surveyed
Crispin Rendon	9
Bill Lydecker	7
Mike Fisher	6
John Luther and Susanne Methvin	6
Darrell Hutchinson	6
Chris Conard and Kimya Lambert	5
Dan Guthrie	5
Pam Williams	4
Ginny Short	4
Russell Almaraz	4

Moore, Nancy Mori, Suzanne Morron, Gerald Mugele, Jerre Murphy, Gordon Murphy, Sue Murphy, Ted Murphy, Jean Myers, George Nash, Kelley Nelson, Nancy Nelson, Wallace Neville, Renee New, Maggie Nunes, Michelle Ocken, D. O'Keefe, Rodney Olsen, Jennifer O'neal, Regena Orr, William Orr, Ed Pandolfino, Becky Parsons, Kay Partelow, Warren Patten, Jennifer Patten, Janna Pauser, Mark Paxton, Fraser Pembeiton, Barbara Pendergrass, David Perrin, Sarah Perrin, Marilynn Perry, Dawn Peterka, Paula Peterson, Randall Peterson, Susan Peterson, Carole Petrash, Shawn Petrash, David G. Philled, Sarah Pitzer, Ken Poerner, Kathy Porter, Marian Porter, Catherine Portman, Bob Power, Ted Raczek, Corina Rahmig, Troy Rahmig, Siddharthan Ramachandramurthi, Art Ramirez, George Rawley, Tricia Reed, Crispin Rendon, Virginia Rhodas, Michael Richard, Bob Richmond, Mike Richter, Matt Ritchie, Michael Robertson, Caroline Rodgers, Tobias Rohmer, Ann Romer, Sarah Ross, Patricia Rouzer, Jim Rowoth, Suzanne Ruckle, Tim Ruckle Jr., Tim Ruckle Sr., Ruth Rudesill, Michael Ruffino, Heather Ryan, Jeff Ryan, Thomas Ryan, Jennifer Rycenga, Donna Sadowy, Nancy Sage, John Santo, Fran Scarlett, Diana Scheel, Lexie Scheel, John Schick, Paul Schorr, Nancy Schorr, Mauricio Schrader, Steve Schwartz, Katie Schwartz, Steve Scott, Jeff Seav, Norman Self, Tracey Sharp, Kathy Sharum, Jackson Shedd, Kathy Shick, Robert Shields, Carolyn Short, Ginny Short, Rodney Siegel, Matthew Simes, Mike Skram, Dale M. Smith, Greg Smith, Michael W. Smith, Curtis Snyder, Tate Snyder, Susan Stanton, Jim Steinert, Sarah Stier, Steve Stocking, Mike Stockton, Brad Stovall, Bruce Strang, Nancy Strang, Linda Swanson, Dan Tankersley, Ian Taylor, Lynn R Thomas, Jennifer Thompson, Christine Tischen, Christine Tisher, Gene Troetschler, Ruth Troetschler, Jeff Trow, Lisa Twiford, Linda Vallee, Ann Verdi, Chuck Verturri, Chantal Villeneuve, Jamie Visinoni, Jim Waddell, Lisa Wadley, Dave Wagner, Annette Waite, Lucy Waite, Zach Wallace, Dee Warenycia, Dean Webb, Daniela Wersin, Kimberly West, Liz West, V. Wheeler, Jonathan Widdicombe, Bruce Wilcox, Bob Wilkerson, Anne Williams, Dan Williams, James Williams, M. Williams, Pam Williams, Bruce Williford, Michael Wilson, Carrie Wingert, Gary Woods, Aaron Works, Lois Wren, Rick Wulbern, Faith Yamane, Chad Young, Ryan Young, and Bill Zachman.

**** Please let us know if your name is missing from this list!****

CALIFORNIA Burrowing Owl Symposium

The Proceedings of the 2003 California Burrowing Owl Symposium, including 20 scientific papers about Burrowing Owls in California, have been published as Bird Populations Monograph No. 1 by The Institute for Bird Populations and Albion Environmental. To learn more about the monograph or to purchase a copy, please visit:

http://www.albionenvironmental.com/

SPECIAL THANKS TO OUR FUNDERS:

National Fish and Wildlife Foundation

Pacific Gas and Electric Company

California Dept. of Fish and Game

A very generous anonymous donor

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Exhibit 657

Burrowing Owl Population Size in the Imperial Valley, California: Survey and Sampling Methodologies for Estimation

Final Report

Submitted to:

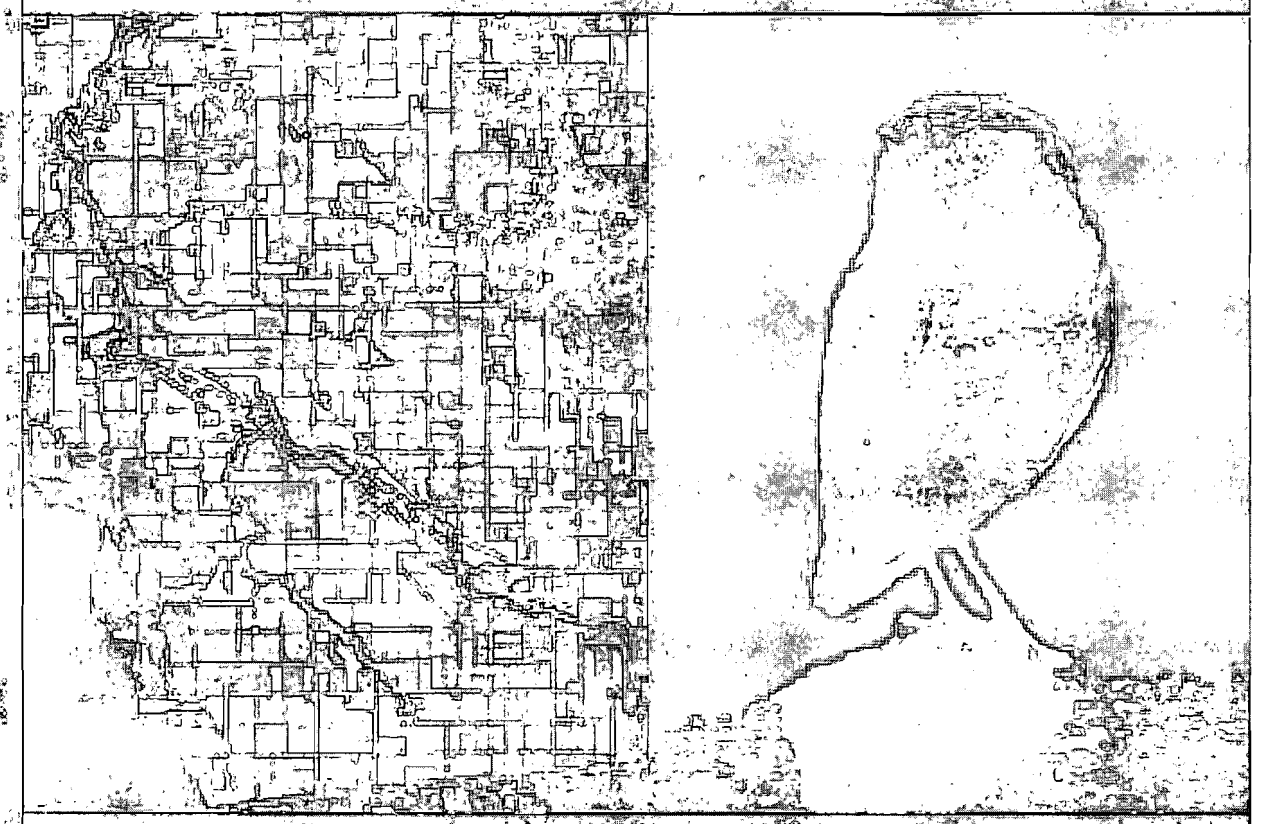
Imperial Irrigation District
333 E. Barioni Boulevard
Imperial, California
92251

Submitted by:

Bloom Biological, Inc.
13511 Hewes Avenue
Santa Ana, California
92705

For work performed under

Imperial Irrigation District
Service Agreement #
2110000664



Jeffrey A. Manning, Author / Principle Investigator

Bloom Biological, Inc.
13511 Hewes Avenue
Santa Ana, California 92705

Manning Biological Research
1653 Conesboga Road
Moscow, Idaho 83843

Wildlife Research Institute, Inc.
19030 Highland Valley Road
Ramona, California 92065

April 15, 2009

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Burrowing Owl Population Size in the Imperial Valley, California: Survey and Sampling Methodologies for Estimation

Final Report

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Submitted to:

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13611 Hewes Avenue
Santa Ana, California 92705

April 15, 2009

Jeffrey A. Manning
1868 Conestoga Road
Moscow, Idaho 83843 USA

Disclaimer: The authors designed, analyzed, and interpreted the results herein to the best of their abilities. As of the date of this report, the information herein is accurate to the best of the authors' knowledge, and reflects their best recommendations for monitoring the abundance of burrowing owls in the Imperial Irrigation District's Service Area in the Imperial Valley, California USA. The authors are not responsible for problems that may arise during the implementation of the recommended protocols or for new information or interpretations that may change the understanding of the results or recommendations presented herein.

Recommended citation:
Manning, J. A. 2009. Burrowing Owl population size in the Imperial Valley, California: survey and sampling methodologies for estimation. Final report to the Imperial Irrigation District, Imperial, California, USA, April 15, 2009.

FOREWARD

Jeffrey A. Manning produced this report under a subcontract between Bloom Biological, Inc. and Manning Biological Research, dated March 10, 2007 and in accordance with the Final Detailed Study Approach for a Burrowing Owl Population Study submitted to the Imperial Irrigation District (IID – Operational Headquarters, 333 E. Barioni Blvd., Imperial, CA 92251), dated January 31, 2007. This report was prepared as part of the IID's mitigation program for the San Diego/ IID Water Transfer project. The study was funded by the Water Transfer project Joint Powers Authority, and the study was conducted under the direction of the Water Transfer Implementation Team.

This report stems from a collaborative effort by Jeff Manning, Bloom Biological, Inc., and the Wildlife Research Institute, Inc. Having conducted more than 40 years of research on southern California Burrowing Owl populations and other raptors, Bloom Biological Inc. contributed baseline natural history information that was used to develop the original research proposal and provided the financial and administrative infrastructure for the project. Jeff Manning developed the study designs, field protocols, and methods of data collection (with reviews and recommendations by W. R. Gould, B. Manly, and others), was the principle field investigator, performed the analyses (with the collaborating coauthors of respective chapters), and authored the reports. He also selected, trained, and supervised field biologists. The Wildlife Research Institute, Inc. hired the selected field biologists, provided information on Burrowing Owl natural history during the 2006 pilot study, and assisted in the training of field biologists. Their senior biologists also assisted in the collection of data during the 2006 pilot study.

I, with Bloom Biological, Inc. and the Wildlife Research Institute, Inc., would like to especially thank Mary Coolidge, Paula Graff, and Scott Thomas for their work as Field Crew Managers, and Caren Goldberg and Stacie Robinson for their work as Statistical Analysts; they all provided recommendations that greatly improved various aspects of field activities, assisted in training field biologists, and spent endless hours to creative problem solving that contributed greatly to the success of the project. Jason Bone of CH2M Hill provided digital data on the IID's rights-of-way. Jeff Tupen of CH2M Hill provided valuable insight into interpreting aspects of the HCP and facilitating and coordinating communications with the Water Transfer Implementation Team. Caren Goldberg provided valuable comments on the general readability of earlier versions of this report. Lastly, this project would not have succeeded without the dedication and hard work of the 66 field biologists listed in Appendix I, who collected standardized survey, behavioral, and experimental field data during the 3 year-period. We thank them all.

Jeffrey A. Manning
Manning Biological Research
1868 Conestoga
Moscow, Idaho 83843

EXECUTIVE SUMMARY

The western Burrowing Owl (*Athene cunicularia hypugea*) is one of 18 New World Burrowing Owl subspecies, only 2 of which are found in North America (Haug et al. 1993). It is listed by the U .S. Fish and Wildlife Service as a Bird of Conservation Concern in every USFWS Region it occurs in and on the National list (USFWS 2002, Klute et al. 2003). It is listed as threatened or endangered in several U.S. states and has been listed as a species of special concern in 16 other U.S. states, including California (Remsen 1978, James and Espie 1997, Sheffield 1997, USFWS 2002). The Imperial Valley of California supports the largest concentration of Burrowing Owls in its range (Desante et al. 2004), and is the site for the Imperial Irrigation District's (IID – Operational Headquarters, 333 E. Barioni Blvd., Imperial, CA 92251) Colorado River Water Conservation and Transfer Project (Final EIR/EIS, dated June 2002). In response to requirements in the draft Habitat Conservation Plan (HCP) and other authorizations associated with the Water Conservation and Transfer Project, the IID issued a request for proposals (Qualifications Request 531) to design and implement a Burrowing Owl population investigation. The overall objective was to estimate the relative abundance and distribution of Burrowing Owls throughout the non-submerged portions of the 500,000-acre HCP Study Area, which encompasses the agricultural matrix of the Imperial Valley. These surveys for Burrowing Owls in the HCP Study Area were to focus on the IID's rights-of-way and service areas that parallel irrigation canals, drains, and ditches, including the All American Canal, and be considered as the initial phase of a 3-phase "Effective Monitoring" strategy described in section 4.5.2 of the HCP.

The proposal for this work was submitted under a partnership between Peter H. Bloom of Bloom Biological, Inc (13611 Hewes Avenue, Santa Ana, California 92705), Jeffrey A. Manning of Manning Biological Research (1868 Conestoga Rd., Moscow, Idaho 83843), and Jeff Lincer of the Wildlife Research Institute, Inc. (18030 Highland Valley Road, Ramona, California 92065). On February 1, 2006, the IID awarded Bloom Biological, Inc. a contract to further design and conduct a proposed stratified random sampling mark-recapture survey methodology for Burrowing Owls developed by Jeffrey A. Manning. The scope of that work entailed the development and implementation of detailed survey and sampling methods during 2 consecutive spring seasons, from which to provide estimates of population size and a validated method to survey for Burrowing Owls within the HCP Study Area in subsequent years. This was later amended by the Water Transfer Implementation Team (IT) on March 20, 2006 to include a pilot study during April and May, 2006, prior to implementing the originally proposed 2-year effort. The objective of the pilot study was to assess probabilities of detection and determine the best survey method (mark-recapture versus removal), times of day, and minimum number of repeat sampling occasions that would be necessary to balance accuracy of abundance estimates with effort (cost) during the 2-year population study.

This final report was developed in accordance with guidance from the IT, the requirements of the HCP and other Water Transfer related authorizations, and includes findings from a series of retrospective studies and field experiments (including a pilot study) conducted on Burrowing Owls during daylight hours in the HCP Study Area. These studies were conducted during the prehatch stage (April) of the Burrowing Owl

breeding cycle in 2006, 2007, and 2008. Retrospective studies and their associated analyses followed rigorous scientific methods based on applying the information theoretic approach with multiple working hypotheses (Chamberlin 1890, 1965; Burnham and Anderson 2002), novel techniques that were tested and validated, random sampling or complete censuses, and/or bootstrapped simulations. Field experiments involved experimental controls, randomly assigned treatments, random sampling, and replication.

All surveys were conducted by biologists with a minimum of a bachelor's degree in biology or related field, formal training in the scientific method, ≥1 years experience conducting avian surveys, or demonstrated abilities conducting wildlife population surveys. All field biologists received extensive classroom and field training in order to standardize the collection of survey data.

The topics presented here correspond to those listed in the detailed study approach titled "Final Detailed Buow Study Approach Section 5.2 of QR 531," included in the IID's Work Order No. 2 (8100000664), dated January 31, 2007, as amended.

The primary objectives were to:

1. Provide accurate annual estimates of relative Burrowing Owl abundance and distribution in the HCP Study Area over a 2-year study period.

2. Develop and validate a repeatable sampling and analysis methodology that optimizes the accuracy of annual estimates of population abundance and distribution while minimizing costs.

Amendments to the approaches used to achieve the above objectives were made after independent peer reviews were provided by Dr. W. Gould (New Mexico State University, Las Cruses; January 8, 2007) and B. Manly (West, Inc, Cheyenne, Wyoming; August 22, 2007) and as new information was made available. These amendments include:

1. Use of a grid with a standardized 3x3-Km grid cell size to evaluate spatial autocorrelation in abundance of owls in lieu of linear IID right of ways. These grid cells would also represent standardized sampling units for all subsequent analyses. This approach was approved by the Water Transfer IT on May 9, 2007, and the size of grid cells approved by Brad Norling of the IID on August 22, 2007 and also by the IT in September 2007.

2. Use of a 110-m buffer to surround point-coordinate-based Burrowing Owl locations for estimating unbiased estimates of male Burrowing Owl population sizes from point-coordinate-based closed capture-recapture data. The approach to examine the most appropriate buffer size was approved by the IT on May 9, 2007, and the 110-m buffer size was approved by Brad Norling of the IID on August 22, 2007 and (by email) by the IT on Sept 17, 2007.

3. Use of remote sensing crop data as a correlate of male Burrowing Owl territory abundance. The initial approach of analyzing remote sensing crop data was part

of the approved detailed study approach, but final approval to use the results to predict abundance was emailed by the IT on September 17, 2007.

4. Disturbance experiment approved by Bruce Wilcox of the IID, April 2008

5. Comparison of double and single drain surveys (in response to requests made by the IT and Dr. W. R. Gould's independent review and recommendation, dated 8 January 2007 and the IT's request).

6. Use of summed estimates of local population abundances to validate long-term stratified sampling monitoring design (in response to Dr. W. R. Gould's independent review and recommendation, dated 8 January 2007).

This report is divided into 20 chapters, with subsequent chapters building upon information from former chapters. Due to the numerous novel scientific approaches applied by individual experts here, the format of this report follows that widely used and accepted by the scientific community, including a listing of authors under each chapter heading (e.g., see Barclay et al. 2007. Proceedings of the California burrowing owl symposium, November 2003. Bird populations monographs No. 1. The Institute for Bird Populations and Albion Environmental, Inc., Point Reyes Station, CA).

In Chapter 1, I provide a general introduction, objectives, and description of the study area. In Chapters 2-9, I focused on the development of an efficient survey method that produced unbiased, precise estimates of abundance. Chapter 10 involved the calculation of maximum likelihood estimates of local male Burrowing Owl territory abundance for each 3x3 km grid cell across the study area in 2007. In Chapters 11-13, I identified correlates of abundance and occupancy with the intention of evaluating the efficacy of using those correlates as surrogates of abundance for stratifying the HCP Study Area prior to subsequent population surveys. In Chapters 14-19 I developed, tested, validated, and recommended a stratified random sampling methodology with the survey method embedded into it to improve precision of population estimates and reduce costs. Chapter 20 provided a brief list of recommended future research directions divided into two sections: 1) those intended to improve the accuracy and reduce costs of population monitoring, and 2) those intended to improve the understanding of the status of the Burrowing Owl population and factors that potentially limit or regulate it.

Key points from this study include the following:

1. Diurnal home ranges of male Burrowing Owls ranged from 0.01 to 2.14 hectares (to 5.30 acres), with an average of 0.32 +/- 0.09 hectare (~0.80-acre). Males restricted 97% of diurnal movements to less than 110 m from their burrow site. Diurnal home ranges were distinct and non-overlapping.

2. Availability of Burrowing Owls (which differs from the probability that an owl was detected, given that it was available for detection) was best explained by temperature, with "availability" decreasing as temperature increased.

3. We recommend single-stop car surveys over two-stop car surveys (surveying both sides of drain feature) or foot-based surveys. Surveying from one side of a drain is recommended over surveying from both drain sides, as the latter produces no substantial reductions in bias over the former (both had about 20% bias range).

4. We recommend a three-pass (e.g., 3 survey occasion) closed population capture-recapture approach over the four-pass approach used in 2007 and 2008: the fourth pass provided only limited additional power, and is not justifiable given the additional effort required. Survey passes are conducted on separate days.

5. Of many potential environmental correlates of owl abundance investigated, the best-fit model (i.e., best correlates) included number of available burrows and presence of alfalfa three years prior to the 2007 survey effort. Based on these results, we initially recommended that these two variables could be used to stratify the study area in future survey efforts. However, after additional analyses in the later chapters, we concluded that it would not be advantageous to use these two variables in stratifying the HCP Study Area, and provided an alternative.

6. Abundance of Burrowing Owls in the study area was estimated at 3,557 male owl territories (= breeding pairs) in 2008. This represented a 27% decline from the 2007 estimate of 4,879 territories. These numbers are considerably lower than prior estimates by other researchers (e.g., Desante et al. 2004 estimated approximately 6,000 territories). The decline in abundance between 2007 and 2008 was detected in most (n=206, 75%) of the 274 3x3 km grid cells used to estimate local abundances across the study area. Substantial abundance declines (>50%) between 2007 and 2008 were detected in over 20% of the grid cells.

7. We present the minimum number of grid cells (of total n=274 in Imperial Valley) to be sampled in future burrowing owl surveys to detect a targeted percent-change in abundance. For example, the abundance estimate resulting from surveying 119 randomly-selected grid cells would produce estimates that would be within 10% of the true population size. This would allow the detection of a change in abundance as small as 20% between survey periods. However, stratified random sampling improved the ability of detecting a change to as low as about 10%.

8. The stratified random sampling methodology requires that the study area be re-stratified prior to each population survey. The best method to stratify is based on BUOW abundance, which can be obtained by a valley-wide single-pass census of owls just prior to selecting a random sample to complete capture-recapture surveys. After this single census, the sample of grid cells to be surveyed (e.g., 119) could be randomly selected and surveyed with only 2 additional passes. By combining census data with the data from the 2 additional passes, a total of 3 survey passes (occasions) would occur in the randomly selected grid cells. With a sample of 119 grid cells, this could produce an estimate that would enable detection of a 10% change in between-year abundance of male Burrowing Owl territories.

TABLE OF CONTENTS

FORWARD
Jeffrey A. Manning iii

EXECUTIVE SUMMARY
Jeffrey A. Manning iv

Chapter 1. GENERAL INTRODUCTION AND STUDY AREA
Jeffrey A. Manning 1

Chapter 2. SPACE USE AND AVAILABILITY OF BREEDING MALE BURROWING OWLS DURING DIURNAL POPULATION SURVEYS
Jeffrey A. Manning, Caren S. Goldberg, Peter H. Bloom, and Scott E. Thomas 5

Chapter 3. EFFECTS OF SURVEY METHODS ON BURROWING OWL BEHAVIORS (*Amendment 4*)
Jeffrey A. Manning and Robb S. A. Kaler 15

Chapter 4. SINGLE VERSUS DOUBLE SURVEY PASSES (*Amendment 5*)
Jeffrey A. Manning 21

Chapter 5. POINT-COORDINATE CAPTURE-RECAPTURE TECHNIQUE TO PRODUCE UNBIASED CLOSED CAPTURE-RECAPTURE ESTIMATES OF MALE BURROWING OWL TERRITORY ABUNDANCE (*Amendment 2*).
Jeffrey A. Manning and Caren S. Goldberg 28

Chapter 6. NUMBER OF SURVEY OCCASIONS
Jeffrey A. Manning and Caren S. Goldberg 37

Chapter 7. CLOSED-POPULATION CAPTURE-RECAPTURE SURVEYS IN 2007 (*Objective 1, Task 1*).
Jeffrey A. Manning 45

Chapter 8. MAXIMUM LIKELIHOOD ESTIMATE OF MALE BURROWING OWL TERRITORY ABUNDANCE IN THE HCP STUDY AREA IN 2007 (*Objective 1, Task 4*)
Jeffrey A. Manning 52

Chapter 9. EVALUATION OF SPATIAL AUTOCORRELATION IN MALE BURROWING OWL TERRITORY ABUNDANCE AND THE DETERMINATION OF A STANDARDIZED SAMPLING GRID (*Objective 1, Task 2; Amendment 1*).
Jeffrey A. Manning and Stacie Robinson 55

Chapter 10. MAXIMUM LIKELIHOOD ESTIMATES OF LOCAL MALE BURROWING OWL TERRITORY ABUNDANCE IN 2007 (*Objective 1, Task 3; Amendment 6*)
Jeffrey A. Manning 63

Chapter 11. DATASETS OF POTENTIAL CORRELATES OF LOCAL MALE BURROWING OWL TERRITORY ABUNDANCE IN 2007 (*Objective 2, Task 1, Amendment 3*)
Jeffrey A. Manning 71

Chapter 12. THE RELATIVE IMPORTANCE OF POTENTIAL CORRELATES OF MALE BURROWING OWL TERRITORY ABUNDANCE (*Objective 2, Task 2*)
Jeffrey A. Manning and Caren S. Goldberg 81

Chapter 13. POTENTIAL CORRELATES OF AREA OCCUPANCY BY MALE BURROWING OWLS *(Objective 2, Task 3)*
Jeffrey A. Manning and Caren S. Goldberg 90

Chapter 14. ELIMINATION OF AREAS DURING FUTURE SURVEYS DUE TO THE ABSENCE OF MALE BURROWING OWL TERRITORIES *(Objective 2, Task 4)*
Jeffrey A. Manning 93

Chapter 15. DEVELOPMENT OF A STRATIFIED RANDOM SAMPLING METHODOLOGY TO SURVEY FOR AND ESTIMATE MALE BURROWING OWL TERRITORY ABUNDANCE *(Objective 2, Task 5; Amendment 6)*
Jeffrey A. Manning and Caren S. Goldberg 95

Chapter 16. MAXIMUM LIKELIHOOD ESTIMATES OF LOCAL MALE BURROWING OWL TERRITORY ABUNDANCE IN 2008 *(need for Objective 2, Task 6; Amendment 6)*
Jeffrey A. Manning 106

Chapter 17. VALIDATION OF STRATIFIED RANDOM SAMPLING METHODOLOGY TO SURVEY FOR AND ESTIMATE MALE BURROWING OWL TERRITORY ABUNDANCE *(Objective 2, Task 6; Amendment 6)*
Jeffrey A. Manning and Caren S. Goldberg 112

Chapter 18. RECOMMENDED SAMPLING METHODOLOGY WITH OPTIMAL ALLOCATION OF EFFORT TO SURVEY FOR AND ESTIMATE MALE BURROWING OWL TERRITORY ABUNDANCE
Jeffrey A. Manning 118

Chapter 19. DEMONSTRATED USE OF ABUNDANCE ESTIMATES FOR CALCULATING LOCAL FINITE RATES OF POPULATION CHANGE
Jeffrey A. Manning 125

Chapter 20. RECOMMENDED FUTURE RESEARCH DIRECTIONS
Jeffrey A. Manning 131

LITERATURE CITED 133

Appendix I. FIELD BIOLOGISTS
Jeffrey A. Manning 142

Appendix II. ACCURACY OF POINT COORDINATES AS LOCATIONS OF BURROWING OWLS
Jeffrey A. Manning 143

Appendix III. REMOTE CLASSIFICATION OF CROPS FROM 2003-2007
Jeffrey A. Manning and Mike Falkowski 147

Appendix IV. INCIDENTAL OBSERVATIONS OF DEAD BURROWING OWLS IN 2006, 2007, AND 2008
Jeffrey A. Manning 168

Appendix V. LOCATIONS OF BANDED OWLS IN 2006, 2007, AND 2008
Jeffrey A. Manning 172

Appendix VI. SELECTED COMMENTS AND REVIEWS 179

Chapter 1

GENERAL INTRODUCTION AND STUDY AREA

JEFFREY A. MANNING

GENERAL INTRODUCTION

The western Burrowing Owl (*Athene cunicularia hypugea*) is listed by the U .S. Fish and Wildlife Service as a Bird of Conservation Concern in every USFWS Region it occurs in and on the National list (USFWS 2002, Klute et al. 2003). It is listed as threatened or endangered in several U.S. states and has been listed as a species of special concern in 16 other U.S. states, including California (Remsen 1978, James and Espie 1997, Sheffield 1997, USFWS 2002). The Imperial Valley of California, USA (32° 58' N, 115° 31' W) supports the largest concentration of Burrowing Owls in its range (Coulombe 1971, Desante et al. 2004), and is the site for the Imperial Irrigation District's (IID – Operational Headquarters, 333 E. Barioni Blvd. Imperial, CA 92251) Colorado River Water Conservation and Transfer Project (Final EIR/EIS, dated June 2002). As part of that project, a draft Habitat Conservation Plan (HCP) was prepared, and the Burrowing Owl was included as a covered species in the HCP.

The HCP specified measures to avoid, minimize, and compensate for potential impacts to Burrowing Owls resulting from the IID's activities, and specified Burrowing Owl monitoring requirements. However, the status and trends in the Burrowing Owl population within the HCP Study Area are largely unknown. Only one study has estimated the size of the Burrowing Owl population in this region (Desante et al. 2004). They surveyed 6% of the Imperial Valley, and estimated the population to be between 3,405 and 7,795 pairs. Because accuracy of abundance estimates is important for species-specific monitoring plans (Atkinson et al. 2004) and making well informed adaptive management decisions, increased accuracy is needed in estimating the Burrowing Owl distribution and population size in the HCP Study Area.

Prior to initiating a long-term population monitoring program for Burrowing Owls along the IID's rights-of-way and service areas that parallel irrigation canals, drains, and ditches within the non-submerged portions of the proposed 500,000-acre HCP area (HCP Study Area), a standardized sampling design that minimizes the required sample size, optimizes the allocation of survey effort, and reduces costs while maintaining high levels accuracy at all stages of the survey is needed. Although range-wide surveys have been recommended (Holroyd et al. 2001), no statistically rigorous broad-scale Burrowing Owl population estimation has been conducted, except for a statewide survey by Desante et al. (2007). Guidelines for conducting standardized visual surveys prior to development in an area have been developed by numerous non-governmental organizations and regulatory agencies across the southwest (California Burrowing Owl Consortium 1997, Arizona Game and Fish Department 2007, New Mexico Department of Game and Fish 2007), but these guidelines are not suitable for determining the appropriate level of sampling and surveying needed to minimize cost while maintaining accuracy in a large area with a high

abundance of owls like that found in the HCP Study Area. Additionally, factors that affect detection of owls during the breeding season have been reported for populations in the northwest and central United States (Conway et al. 2008), but because the range of environmental conditions determined to be important in that study differ dramatically from that found in the Imperial Valley, these results should not be inferred to the HCP Study Area. Additionally, while Conway and Simon (2003) provide a rigorous comparison of detection probabilities among three methods of surveying for Burrowing Owls, other survey methods are available, and the applicability of using these survey methods in the HCP Study Area has yet to be evaluated.

Two sources of error that influence the precision of population estimates are measurement error and sampling error (Cochran 1977). Measurement error occurs when an observer fails to detect an animal that was available for detection during a survey, also referred to as detection probability (Diefenbach et al. 2007). This source of error can be attributed to habitat and/or environmental conditions, animal behaviors, observer fatigue, and survey methodology, among numerous other factors. Methods of estimating abundance commonly adjust raw counts by an estimated detection probability (Diefenbach et al. 2007), but lower detection probabilities coincide with lower precision of abundance estimates. Measurement error can be reduced by implementing a variety of techniques, including the use of skilled observers, application of standardized survey protocols, selection of survey times to maximize visibility and minimize misidentification of target animals, training to increase consistency and accuracy, and use of field instruments with high accuracy.

Sampling error is associated with experimental design and sampling of a population (Kuehl 1994). Time and money limitations typically constrain population surveys to a sample of areas that represent a fraction of the area occupied by the population of interest. Here, each area represents an areal sampling unit, and sampling error refers to the variability in abundance of animals among these sampling units. In these situations, a carefully selected experimental design can reduce sampling error and improve statistical power (Kuehl 1994). Designs such as cluster sampling, randomized block design, and stratified random sampling reduce sampling error by classifying sampling units according to their similarity or dissimilarity and estimating abundance in each class separately. These designs generally assume that population counts in sample units are without measurement error, which is why it is still important to reduce measurement error when using them.

Steidl et al. (1997:274) provide an elegant example that illustrates the gains in power when an efficient experimental design and appropriate statistical model for analysis are used. The remainder of this paragraph is an excerpt from that paper. "The effect of recreation on breeding bald eagles ... was investigated by measuring brood behavior of eagles with people camped at distances of 500 and 100 m from nests (Steidl 1995). Assuming these data were collected with a completely randomized design, the null hypothesis of no difference in the percent day that eagles spent brooding with people camped at these 2 distances could not be rejected ... However, power to detect a 20% effect with this design ... was low ..., indicating that the results were inconclusive.

Eagle nesting behavior changes rapidly as nestlings mature (Steidl 1995), and [the] completely randomized design [above] did not account for this known source of variability. Instead, a crossover design was used (Jones and Kenward 1989), where both treatment and control were applied in succession to the same experimental unit (nest). This design eliminated variability due to nestling age between nests. The null hypothesis of no difference in behavior between distances [people were camped] was rejected with this approach ..., indicating that eagle behavior changed when people camped near nests."

Because abundance of owls is expected to be unevenly distributed across the HCP Study Area, a simple random sample of areas would likely lead to imprecise population estimates of male Burrowing Owl territories (Caughley 1977:27; Williams et al. 2002:247). An accurate estimate of population size can be obtained with sampling designs that account for the size, shape, number, and placement of sampling units across areas where abundance is unevenly distributed (Caughley 1977:27; Williams et al. 2002:247). This is a critical issue in population monitoring because increased precision translates to an increase in the ability to detect changes in population size. Imprecise estimates only allow for detection of large changes in a population.

A commonly used design to estimate the size of wildlife populations in large areas where abundance is unevenly distributed is stratified random sampling (Caughley 1977:27; Williams et al. 2002:249). The area supporting the total population of interest is subdivided into areal sampling units, and these are categorized according to their similarity in animal abundance (e.g., low, medium, and high). These categories are referred to as strata, and a random sample of units is drawn separately from each stratum. Animals are counted in the randomly sampled units and the strata abundances are summed to estimate a total population size. This stratification of units into similar abundances reduces sampling error within strata and the estimated total population estimate.

This report provides the results from a series of retrospective and experimental studies conducted over a 3-year period in the HCP Study Area, beginning with a pilot study in 2006. Our general objective was to develop and validate a repeatable stratified random sampling and analysis methodology that optimizes the accuracy of annual estimates of population abundance and distribution while minimizing costs. Secondarily, we provide unbiased estimates of local and HCP-wide Burrowing Owl abundance and distribution and demonstrate an application of these estimates in calculating annual rates of population change over the last 2 years of the study. Except where otherwise emphasized, this study focused on observations of individual owls, with inference drawn to nests and territories where appropriate. For retrospective and survey-based analyses, my general approach was to use the information theoretic approach to test multiple working hypotheses (Chamberlin 1890, 1965; Burnham and Anderson 2002); but, in some cases where inferential statistics were applied, and a P-value of <0.1 was used for determining significant differences. Field experiments used inferential statistics with a P-value of <0.05, unless otherwise stated.

This study was funded by the IID, with oversight provided by the IT. Bloom Biological, Inc. held the contract with the IID, established subcontracts with Jeff Manning and the Wildlife Research Institute, Inc., and provided information on the natural history of owls. Jeff Manning developed the study designs, field protocols, and methods of data collection (with reviews and recommendations by W. R. Gould, B. Manly, and others), was the principle field investigator, performed all analyses (with the collaborating coauthors of respective chapters), and authored all reports. He also managed purchases and the budget and selected, trained, and supervised field biologists. The Wildlife Research Institute, Inc. hired the selected field biologists, provided input during the pilot study, and assisted in the training of field biologists. Their senior biologists also assisted in the collection of data during the pilot study.

GENERAL DESCRIPTION OF STUDY AREA

This study was conducted in the agricultural matrix of the Imperial Valley of California, USA (32° 58' N, 115° 31' W), an important region for Burrowing Owls that supports the largest population in North America (Coulombe 1971, Desante et al. 2004). Specifically, the HCP Study Area included all non-submerged portions of the 500,000-acre HCP Study Area, and surveys were conducted where the IID's rights-of-way and service areas paralleled irrigation canals, drains, and ditches, including the All American Canal.

Extensive landscape change occurred in this desert ecosystem during the 20th century, with a large portion of the Imperial Valley cultivated for agricultural production with irrigation water supplied by the Colorado River (Bailey 1994). During this study, fields were intensively managed year-round for irrigated agricultural production, with alfalfa (*Medicago sativa*), Sudan grass (*Sorghum bicolor*), Bermuda grass (*Cyondon dactylon*), and wheat (*Triticum* spp.) as the dominant crops. Agricultural fields were routinely flood irrigated, irrigation drains, canals, and ditches were dredged and maintained for water conveyance, and access roads were graded. Within this agricultural landscape during the course of this study, Burrowing Owls nested almost entirely within or along irrigation drains, canals, and ditches.

Chapter 2

SPACE USE AND AVAILABILITY OF BREEDING MALE BURROWING OWLS DURING DIURNAL POPULATION SURVEYS

JEFFREY A. MANNING, CAREN S. GOLDBERG, PETER H. BLOOM, AND SCOTT E. THOMAS

ABSTRACT. Formulating a baseline understanding of Burrowing Owl space use during the day in the HCP Study Area and the implications of this information on conducting diurnal surveys is important. Here, we showed that male Burrowing Owls occupied small, spatially distinct, diurnal home ranges, restricted 97% of their activities to <110 m from the nest, and remained closest to their nest burrow during mid-afternoon while females were in the burrow. We also found that an increase in nest density coincided with a decrease in diurnal home range size and that diurnal home ranges remained spatially distinct (i.e., no change in the level of inter-home range overlap) when the density of nests increased. We also found that their availability for detection decreased on the mid-day. We concluded that these patterns in diurnal space use would minimize the risk of double counting owls or pairs during diurnal population surveys conducted in the prehatch stage of the breeding cycle and that surveys should be avoided in the mid-day until an estimator of abundance that incorporates availability becomes available.

INTRODUCTION

Like many highly mobile species, Burrowing Owls utilize various locations across their home ranges throughout a 24-hr period. This variation should be identified and accounted for to improve the accuracy of estimates derived from population surveys. For example, the probability of being available for detection (which differs from the probability that an animal is detected, given that it is available for detection) throughout the day (e.g., due to being in a burrow) is likely not to be constant; depending on when a survey is conducted, this variation can bias population estimates (Diefenbach et al. 2007). Many of the current methods used to estimate populations, like distance sampling, double-observer, and sightability (Williams et al. 2002), assume that the probability that an animal is available for detection is 1.0. Thus, information on the availability of individuals for detection and home range use and overlap can be useful in developing standardized survey protocols that increase the accuracy of population estimates, as is specified under the HCP.

Burrowing Owls use their nest burrow as a central place, with activities emanating outward like that of a central place forager (Orians and Pearson 1979, Schoener 1979). During the breeding season, male Burrowing Owls actively defend the immediate vicinity of the nest during the day (Coulombe 1971, Thomsen 1971, Martin 1973, Moulton et al. 2004) and expand their space use at night, with nocturnal home ranges measured at 45 to 184 ha (Gervais et al. 2003, Rosenberg and Haley 2004). Low detection probabilities during nocturnal surveys (Haug and Didiuk 1993, Conway and Simon 2003) may be due to these extensive movements, as owls may be absent from the area being surveyed. This

is a concern for population monitoring because low detection probabilities decrease precision of population estimates (Seber 1982).

Surveys conducted while owls are occupy small diurnal home ranges may avoid these issues and produce highly accurate population estimates if movements of individual owls are short and home ranges show little overlap. However, the probability that an owl is available for detection throughout the day may change, which can bias estimates (Diefenbach et al. 2007). For example, low availability of Burrowing Owls during mid-afternoon surveys in northern California biased population counts 90% below the known population size (Thomsen 1971). Due to these behaviors, sampling throughout the day in northern latitudes, as recommended by Conway et al. (2008), may not provide reliable estimates of population size if this variability is not accounted for.

In this chapter, we focused on formulating a baseline understanding of Burrowing Owl space use and the implications of such on conducting surveys in the HCP Study Area. We estimated the size and level of overlap of diurnal Burrowing Owl home ranges during the prehatch stage of the breeding cycle and explored how these parameters varied with nest density. We further estimated the availability of Burrowing Owls throughout the day, and demonstrated how availability can influence population estimates derived from diurnal sampling.

METHODS

Data Collection

Spatial use of diurnal home ranges

We surveyed resident male Burrowing Owls during the breeding season from 1 April to 1 May 2007. We chose these dates because they corresponded with the prehatching stage of the nesting cycle, when males move little and remain sentinel around the nest entrance while females incubate (Martin 1973, Plumpton and Lutz 1993). We randomly selected 5 linear areas along the irrigation system that contained neighboring owl nests ($n = 40$ nests). We counted all active burrows in each of the 5 areas that contained sign of Burrowing Owl use (e.g., an owl that retreats or flushes from burrow, regurgitated pellets, feathers, nest lining, whitewash, or footprints with an absence of cobwebs; Conway et al. 2008). We considered the burrow entrance with the greatest amount of sign in the vicinity of each male to be the primary burrow entrance, and recorded its Geographic Positioning System (GPS) location. We used the distance between nest burrows that were at each end of a sampling area to estimate the density of nest sites.

We captured 94 resident owls with noose carpets, Bal-Chatris traps, Havahart traps, and mist nets (Collister 1967, McClure 1984, Bloom 1987, Bloom et al. 2007; Federal Bird Marking and Salvage permit 20431 and California Scientific Collector's Permit 801176-02). Each owl was fitted with metal U.S. Fish and Wildlife Service and colored plastic polyvinyl chloride, alphanumeric leg bands. We used the apparent absence of brood patches to assign sex to each banded owl, and verified that the male at each nest site was

banded by conducting visual surveys the following day when we anticipated that females would be incubating eggs in the nest burrow. We used this information and that from counting active nests to derive a true number of active nests. We were unable to capture and band owls in eight nests, but we retained these for observations because they were situated between nests with banded owls, thus enabling us to distinguish them.

We continuously tracked each male for 13 consecutive hours between sunrise and sunset and mapped perch locations every 15 minutes. Observations were conducted with binoculars and a spotting scope, range finder, compass, and GPS unit. Observations were made from vehicles parked at a distance that we believed would not disturb owls (ca. 160 m). We recorded the GPS location of the observer and used the distance and bearing to the owl to map 15-minute owl locations, which were determined during a pilot study to be accurate to <3 m. The flat agricultural landscape enabled us to maintain sight of owls even when they traveled far distances. But, if an observer was unable to locate or verify identification of an owl ≤1 minute before or after a 15-minute time stamp, the location was not recorded.

Availability throughout the day

We conducted time budget surveys of resident Burrowing Owls in the vicinity of eight randomly selected, individual active nests during the prehatching stage of the nesting cycle, from 7-17 May 2006. We surveyed continuously from 06:30-19:30 (PDT), except between 12:30 and 13:30, and recorded the number of minutes within each hour when ≥1 owls were available for detection (e.g., not in a burrow). Again, due to the flat agricultural landscape, we were able to maintain continuous sight of owls even when they traveled far distances.

We examined the relative importance of ambient air temperature, wind speed, and time of day on the probability that Burrowing Owls were available for detection. We included the 2 weather variables because past authors suggested that they reduce detection probability (Shyry et al. 2001, Conway et al. 2008). We recorded ambient temperature (°C) and wind speed (km hr^{-1}) frequently throughout each survey hour with a Kestrel 3000 Pocket Weather Monitor, from which we computed hourly averages throughout the day. Ambient temperature varied from 17 to 41°C, and wind speed varied between 0 and 17 km hr^{-1}.

Diurnal population surveys

To examine how availability of owls throughout the day may affect estimates of population abundance, we counted the number of Burrowing Owl pairs in 12 randomly selected linear areas along the irrigation system between 16 April and 20 May 2006. These areas were independent from those used to assess space use in 2007. Each area was approximately 6.5 km long and was surveyed completely during each hour throughout the day (06:30-18:30 (PDT), except for 12:30-13:30). Surveys were completed by one observer and one driver in a vehicle that traveled 11 km hr^{-1}. We used the same make and model vehicle during all surveys, and positioned vehicles so the

observer had an unobstructed view of the nesting habitats. We followed the same path and direction during each hourly survey. To reduce double counting owls, the observer maintained a field of view in the direction of travel and did not look behind the vehicle. We stopped the vehicle at each owl and mapped the location with a GPS unit. Because females and males typically remain close the burrow during this period of the nesting cycle (Thomsen 1971, Martin 1973), we considered owls <12 m apart to be a nesting pair and recorded them as a single observation.

Statistical Analyses

Spatial use of diurnal home ranges

We measured the distance between an owl's primary nest burrow and its 15-minute locations using ArcGIS 9.2 (ESRI, Redlands, CA). To evaluate distance moved through time of day, we divided these values by the farthest distance an owl moved. We fit a 95% fixed kernel home range utilization distribution to each owl's set of 15-minute locations (Worton 1989), and considered these as diurnal home ranges. We used likelihood cross validation smoothing because it has been shown to be a better procedure for small sample sizes and for obtaining more accurate and consistent estimates in high use areas (Blundell et al. 2001, Horne and Garton 2006).

We assessed the proportional difference in size of diurnal home ranges relative to nocturnal use areas ($\bar{x} = 45.3 \pm 18.2$ ha) measured within our study area (Rosenberg and Haley 2004). We also computed the probability that an owl would cross into a neighboring home range as ½ of the volume of overlap between neighboring diurnal home ranges. To examine if distinct boundaries of diurnal home ranges were maintained at various densities, we used unpaired, two-tailed Student's *t*-tests to determine if the size of diurnal home ranges or the probability of crossing into a neighboring home range differed when density of home ranges increased by 114% (7 owls km^{-1} vs. 15 owls km^{-1}). Statistics were computed using R (Ihaka and Gentleman 1996), *P*-values <0.1 were considered significant, and estimates are presented ± 95% confidence limits.

Availability throughout the day

We computed the proportion of each hour that ≥1 owls were available for detection in a home range throughout the day, and applied an arcsin square root transformation. We fit seven *a priori* linear mixed effects models to these data, and used Akaike's Information Criterion (AIC) to evaluate the relative strengths of the models (Akaike 1973, Burnham and Anderson 2002; Table 2.1). Statistics were computed using R (Ihaka and Gentleman 1996).

Diurnal population surveys

We used the raw counts to compute the proportion of the largest number of nesting pairs observed in the corresponding area during each hourly survey. Estimates are presented ± 95% confidence limits.

RESULTS

Spatial Use of Diurnal Home Ranges

We recorded 1401 diurnal locations of 40 male Burrowing Owls during the prehatch nesting stage in April 2007. Diurnal home ranges (95% fixed kernel) ranged from 0.009 to 2.14 ha ($\bar{x}$ = 0.32 ± 0.09 ha; Figure 2.1), and averaged <1/100th the size of nocturnal use areas previously reported in our study area. Male Burrowing Owls moved short distances through the day, with the shortest occurring in mid-day (e.g., 12.0 ± 3% as far as the maximum diurnal distance moved) and the longest close to sundown (Figure 2.2).

The probability that an owl was present at increasing distances from its nest burrow followed the pattern of a central-place forager, and reached almost 100% at 110 m from a nest burrow (Figure 2.3). Overlap among neighboring diurnal ranges was minimal ($\bar{x}$ = <0.001 ± 0.000001 ha), and did not differ where density of burrows was doubled (Student's t_8 = 1.34, P = 0.20). However, the size of diurnal ranges where density was high (0.38 ± 0.30 ha) was only 39% of that where the density was low (0.98 ± 0.65 ha, Student's t_{18} = 1.82, P = 0.08).

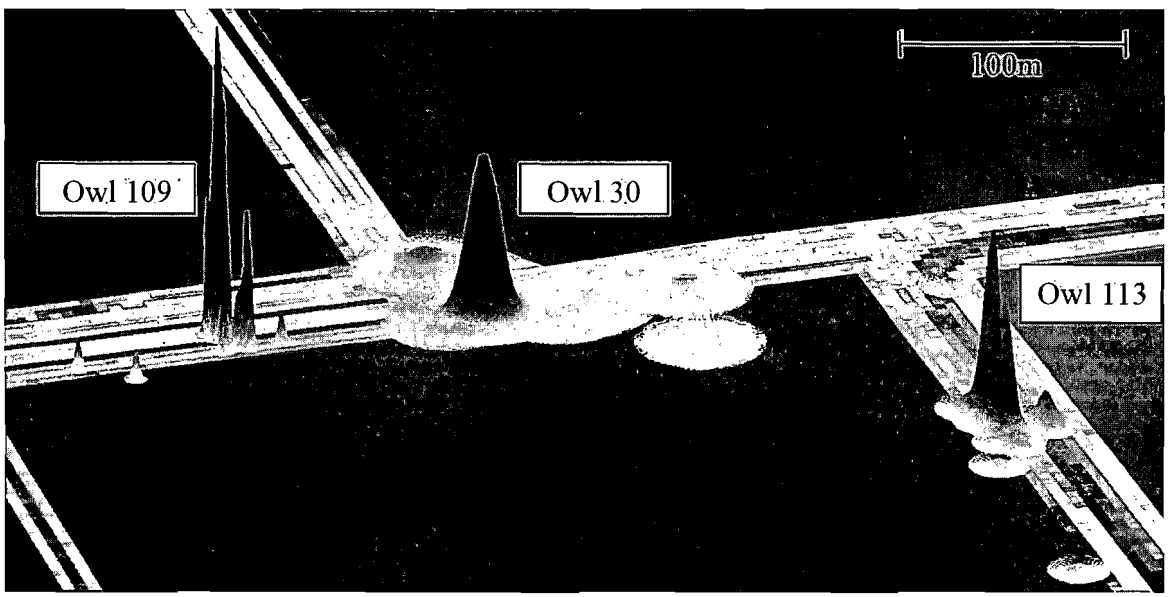


Figure 2.1. Male Burrowing Owl diurnal ranges depicted as 95% fixed kernel utilization distributions along linear irrigation drains (light grey) paralleling dirt roads (white) during the prehatch stage of the nesting cycle in the Imperial Valley, California, April 2007. Solid grey polygons represent agricultural fields.

Availability Throughout the Day

We recorded 142 time budget records in eight home ranges from 16 April 20 May 2006. The best mixed effects model predicted the probability that ≥ one owls was available for detection during a given hour of the day in a diurnal home range as a negative function of temperature [availability = $(\sin(2.13 - 0.03 \times \text{temperature}))^2$, $R^2 = 0.34$, Table 2.1]. The next best model (ΔAIC = 3.6 predicted availability as a 2nd-degree polynomial function of time of day. Availability decreased in mid-afternoon, was lowest (58%) between 1530 and 1630h, and increased to 92% by 17:30 (Figure 2.4).

Diurnal Population Surveys

We counted 93 pairs of Burrowing Owls during hourly surveys in 12 6.5-km nesting areas. Numbers of pairs declined with increasing temperature (Figure 2.4a), which also roughly corresponded with that predicted by our best model for availability throughout the day (Figure 2.4). Numbers of pairs also followed availability throughout the day, declining to the lowest numbers in the mid-afternoon (Figure 2.4b).

Table 2.1. Linear mixed models predicting the proportion of time ≥ one Burrowing Owl is available for detection at a nesting territory as a response to time of day or weather in the Imperial Valley, California April 16-May 20, 2006. Time budget surveys were based on 11-hr observations of 8 nesting home ranges, home ranges were considered random effects, and availability was arcsin square root transformed.

Model	# Parameters	ΔAIC_c
Linear trend (temperature)	2	0
2nd-degree quadratic (time of day)	3	3.6
Linear trend (time of day)	2	5.4
Linear trend (temperature + wind)	3	6.9
Linear trend (wind)	2	7.0
Linear trend (time of day + wind)	3	12.1
2nd-degree quadratic (temperature)	3	12.7

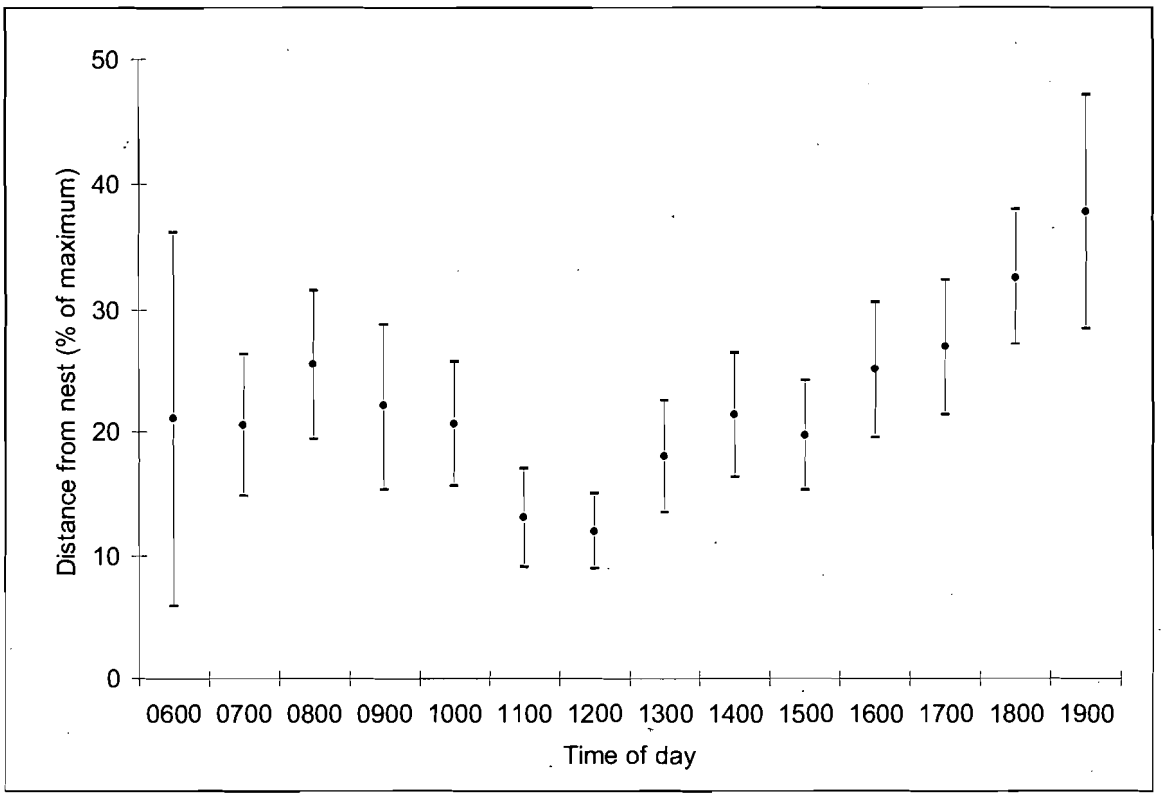


Figure 2.2. Distance (distance/maximum distance) that male Burrowing Owls moved from their nest burrows through time of day during the prehatch stage of the nesting cycle in the Imperial Valley, California, April 2007. Percentages are from 15-minute observations (n = 1,401) of 40 male owls recorded during 13 continuous hours (0600-1900). Error bars represent 95% CI.

CONCLUSIONS AND RECOMMENDATIONS

Spatial use of home ranges by Burrowing Owls was not uniform throughout the day. As suggested by other studies (Thomsen 1971, Moulton et al. 2004), male Burrowing Owls in our study occupied small, spatially distinct, diurnal home ranges. During the day, males restricted 97% of their activities to <110 m from the nest, and remained closest to their nest burrow during mid-afternoon while females were in the burrow. Diurnal activities were confined to <1% of nocturnal use areas as measured in a previous study on Burrowing Owls in this area (Rosenberg and Haley 2004). Our results support Moulton et al.'s (2004) findings that male Burrowing Owls during the breeding season appear to defend a relatively small portion of their nocturnal foraging areas during daylight hours. The small diurnal home ranges we observed may be due to males remaining close to their nest burrows to protect their mate from predation and from unmated males (Thomsen 1971). An alternative explanation is that nest burrows in agricultural landscapes like the Imperial Valley may function as a primary source of escape cover against aerial predators, as we occasionally observed owls entering their burrows when aerial predators (*Buteo, Falco, or Circus* spp.) were present.

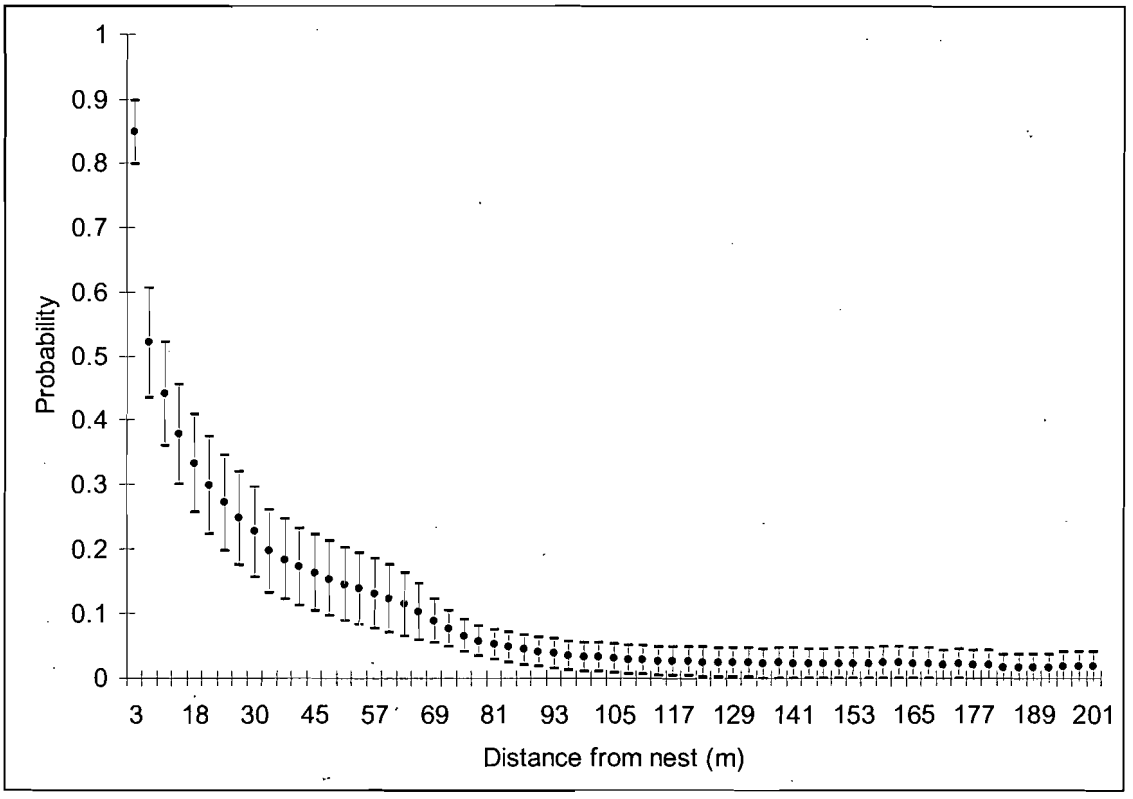


Figure 2.3. Probability that a male Burrowing Owl was present at increasing distances from its nest burrow throughout the day during the prehatch stage of the nesting cycle in the Imperial Valley, California, April 2007. Probabilities are from 95% fixed kernel estimates computed with 15-minute observations (n = 1,401) of 40 male owls recorded during 13 continuous hours (0600-1900). Error bars represent 95% CI.

Although previous studies reported that the number of neighboring nests did not account for the size of nocturnal home ranges during the breeding season (Gervais et al. 2003), we found that an increase in nest density coincided with a decrease in diurnal home range size, as suggested by Haug et al. (1993). We further found that diurnal home ranges remained spatially distinct (i.e., no change in the level of inter-home range overlap) when the density of nests increased. Similarly, Thomsen (1971) reported that Burrowing Owl pairs in northern California with the shortest distance to another nesting pair had the smallest home ranges. Although we did not investigate whether the density of breeding home ranges translated to density dependent demographic rates, we suspect that the spatially distinct diurnal home ranges and high use <110 m from nests we observed may maximize reproductive fitness, as nests <110 m from neighboring nests in Oregon were shown to have lower reproductive success than nests farther apart (Green and Anthony 1989).

Because many population estimation procedures assume that the probability that an animal is available for detection is 1.0 (Otis et al. 1978, Diefenbach et al. 2007), it is important to identify and account for probabilities of availability not otherwise accounted

for when conducting population surveys. Estimates of Burrowing Owl abundance from previous studies have been based on detection probabilities where the probability that an owl was observed was confounded with the probability that an owl was available for detection (e.g., Rosenberg and Haley 2004, Conway et al. 2008). We found that the availability of Burrowing Owls in home ranges throughout the day in the HCP Study Area was best explained by a temperature, although our next best model predicted it as a 2nd-degree polynomial function of time of day, but there was no support for wind.. Availability was highest when temperatures were low (mainly in the morning and late afternoon), and declined as the temperature increased. Availability declined to its lowest level (58%) when it reached the hottest temperatures generally in mid-afternoon. The proportion of the population counted during our independent surveys followed this pattern with temperature and time of day closely, indicating that probabilities of availability <1.0 throughout the hotter afternoon periods bias estimates of Burrowing Owl population abundance based on counts. Likewise, Thomsen (1971) reported that availability declined to its lowest level in the mid-afternoon, and that surveys during that time estimated only 10-25% of the population.

Burrowing Owls maintain small, distinct, non-overlapping diurnal home ranges at various densities during the prehatch stage, when they are most readily surveyed. However, population estimates derived from surveys conducted during the hotter afternoon period will be biased low, as owls are least available for detection during this relatively hot period. We recommend that surveys of Burrowing Owls either incorporate appropriate correction factors for this variability or be conducted in the morning and late afternoon during the prehatch stage to produce the most accurate estimates of population size.

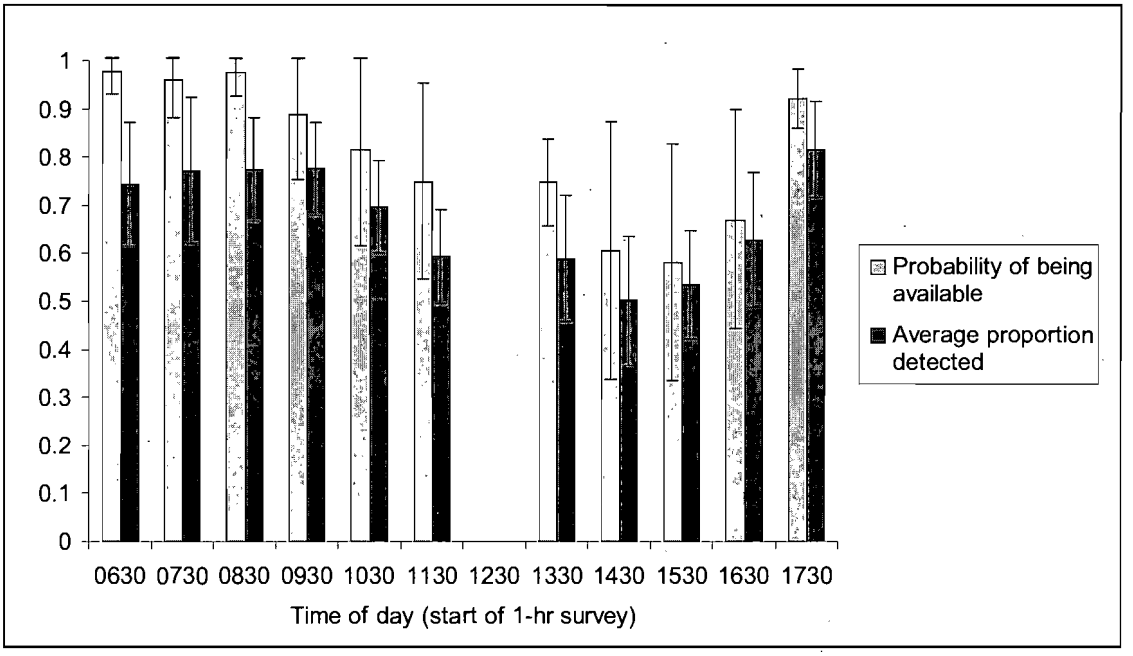


Figure 2.4a. Hourly percentage of time male Burrowing Owls (n = 8) were available for detection (e.g., not in their nest burrow) and hourly average number of breeding pairs (n = 93) detected throughout the day during the prehatch nesting stage in the Imperial Valley, California. Percentages are from time budget surveys and number detected from automobile-based survey counts. Error bars represent 95% CI.

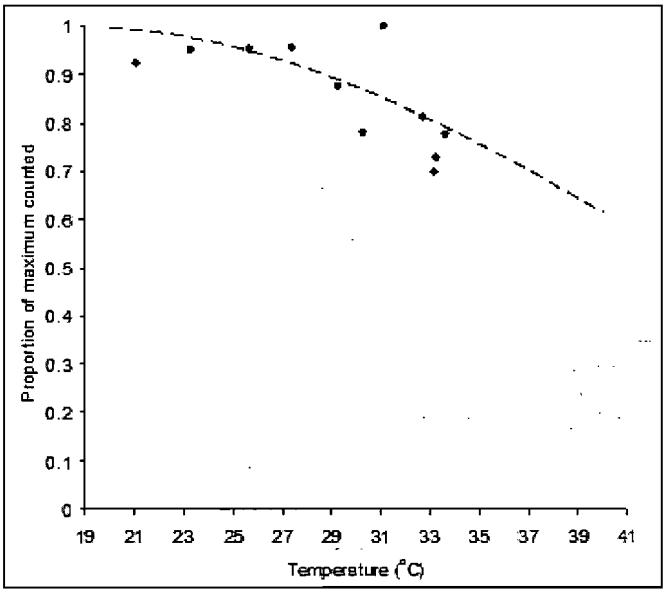


Figure 2.4b. Hourly proportion of maximum Burrowing Owl pairs (n = 93) counted throughout the day from automobile-based survey counts as a function of temperature during the pre-hatch nesting stage in the Imperial Valley, California. Dashed line depicts the best linear mixed model predictions of availability (availability = $(\sin(2.13 - 0.03 \times \text{temperature}))^2$) derived from independent time budget surveys. Temperature is arcsine square-root transformed.

Chapter 3

EFFECTS OF SURVEY METHODS ON BURROWING OWL BEHAVIORS

JEFFREY A. MANNING AND ROBB S. A. KALER

ABSTRACT. Information on the behavioral responses of Burrowing Owls to various methods of surveying in the HCP Study Area would be useful for the development of survey protocols. As part of Amendment 4, we compared the effects of 4 survey methods against an experimental control (no survey) on short-term behavioral responses of Burrowing Owls during the prehatch stage of the breeding cycle. The 4 survey methods included a 2 car that drove by an owl twice and stopping both times, representing the double sided drain surveys described in the HCP. Another involved a car that drove by and stopped once, representing the method we used for conducting the population surveys. We found that an owl was 5 times more likely to be displaced by a passing survey car, 15 times more likely to be displaced by a walking surveyor, 16 times more likely to be displaced by a single car survey stop, and 27 times more likely to be displaced by a double car survey stop. We recommend the single car stop for conducting population surveys across the HCP Study Area because they are more efficient than walking and may reduce short-term responses compared to double car stops, which may help minimize bias associated with double counting.

INTRODUCTION

Due to the large extent of the HCP Study Area, we proposed that surveys be conducted from slow moving (7 mph) vehicles. This approach provides an efficient sampling method because burrowing owls nest and forage near roadsides (Brenckle 1936, Ratcliff 1986, Plumpton and Lutz 1993), with the majority of nests in the HCP Study Area occurring <15 m from the banks of water conveyance structures that parallel roads (Desante et al. 2004, Rosenberg and Haley 2004). Additionally, the HCP made reference to surveying both sides of drains (essentially requiring a vehicle to pass on both sides of a water conveyance structure). However, there is some evidence that locomotion and alertness of Burrowing Owls are correlated with vehicular traffic (Plumpton and Lutz 1993). Thus, multiple passes by a vehicle could disturb owls by flushing them (Plumpton and Lutz 1993), which may increase the probability of inter-territorial overlap we reported in chapter 2. Such disturbances could lead to unintended double counting of unmarked owls, resulting in a positive bias in population estimates.

There is a paucity of studies in the literature regarding the effects of various survey methods (e.g., surveyors with or with vehicles, vehicles that stop versus not stopping when owls are detected) on behaviors of owls. Information regarding how owls respond to various population survey methods can help elucidate possible sources of bias associated with estimates of population size. Survey methods that minimize disturbance may reduce movements, which should reduce double counting and its associated influence on bias while also reducing stress and other ecologically important rates (e.g.,

predation by aerial predators or energy expenditure) for owls. This chapter presents the results from a field experiment we conducted in the HCP Study Area, where we compared the effects of 4 survey methods against an experimental control (no survey) on short-term behavioral responses of Burrowing Owls during the prehatch stage of the breeding cycle.

METHODS

Data Collection

We conducted a field experiment with 1 control (no survey) and 4 methods of surveying owls as experimental treatments (Table 3.1). Between April 25-May 1, 2008, we randomly selected 395 owls along IID-maintained water conveyance structures across the HCP Study Area and randomly assigned one of the above 4 treatments or control to each of the owls, following a balanced design (n = 79 for each treatment group and control). We chose this period because it corresponded with the prehatching stage of the nesting cycle, when females incubate and males remain sentinel outside the nest entrance (Martin 1973, Plumpton and Lutz 1993).

Eight survey teams of 3 biologists in 2 vehicles applied treatments and recorded behavioral responses. One vehicle was designated as the 'observation' vehicle and included a single observer. The second vehicle was designated as the 'treatment' vehicle and included two surveyors. With the exception of color, all vehicles were identical and were required to keep lights off and windows rolled up during treatments.

Upon locating a randomly selected owl, the observer positioned their vehicle along the right-of-way at a vantage point ~50 m from the owl and signaled (via punctuated illumination of the vehicle's taillights) to the surveyors in the treatment vehicle positioned >150 m behind to move to ~100 m behind the observation vehicle. Based on previous observations, we believed that these distances would minimize disturbance to the owl. After the treatment vehicle was in position, both vehicles remained stationary for a 5-minute pre-treatment period to allow the owl to acclimate to the observer vehicle. If during the 5-minutes pre-treatment period the target owl appeared to be disturbed by the presence of the vehicles (head bobbing, multiple flights, repeated looking in the direction of the vehicles), then that owl was excluded from the study.

At the end of the 5-minute pre-treatment period, the treatment vehicle applied the randomly selected treatment. After the survey vehicle departed, the observer remained in the other vehicle for up to 20 minutes and recorded the location of the perch that was at the maximum distance the owl was displaced from its original perch where the treatment was first applied. If the owl returned to <10 m from its original perch <20 minutes after the treatment was applied, we also recorded the time it was displaced and that it returned to its original perch. If the owl did not return within the 20-minute post-treatment period, the observer recorded the location of the perch associated with the maximum distance and time (20 minutes) displaced and ended observations. If an owl departed from the observers view during the treatment or 20-minute post-treatment period and could not be

Table 3.1. Survey methods (treatments) randomly assigned to Burrowing Owls in the HCP Study Area, May 2008.

Survey Method	Description
Control	No surveyors or vehicles present; observed owl from observation vehicle (see below).
Car pass	Vehicle traveled 7 mph and paused for 2 minutes where owl was located before traveling away at 7 mph; the engine remained on and surveyors remained inside vehicle.
Walk	A single surveyor walked along the right-of-way surveying for owls with binoculars.
Single car stop	Survey vehicle traveled 7 mph along right-of-way, stopped at owl, and two surveyors exited the vehicle to record location data for 2 minutes, then resumed driving away from the owl.
Double car stop	This treatment represented the double survey pass initially proposed in the HCP; survey vehicle traveled 7 mph along right-of-way, stopped at owl, and 2 surveyors exited the vehicle to record location data for 1 minute, followed by the departure of the vehicle with the surveyors and the subsequent return of the vehicle within a few minutes to repeat the above for 1 minute (regardless of the owl had moved), at which time the vehicle and surveyors resumed driving away from the owl.

resighted, the observation was abandoned and excluded from the study. If the owl traveled out of the observer's view by going into a burrow, the observation continued until the owl (if ever) reappeared from the burrow, or to 20 minutes, whichever was shorter. For the control, there was no treatment vehicle and the observer recorded the maximum displacement location of the owl during a 20-minute observation period. In addition to above-ground locations, we considered standing on the ground, at burrow entrances, or in burrows as perch locations. All location data were recorded using a Trimble GeoXM, range finder, and compass, with <3-m accuracy.

Statistical Analyses

We used ArcGIS 9.2 (ESRI, Redlands, CA) to measure the maximum distances that owls were displaced. We used a logistic model with a binomial response (displaced, no response) to assess whether the probability that an owl was displaced differed among survey methods. We used the area under a receiver operating characteristic (ROC) curve to assess how well the model parameters predicted when an owl would be displaced (Hanley and McNeil 1982, Heagerty et al. 2000). We used odds ratios to compare how much more likely it was for an owl to be displaced by one survey method over another (Hosmer and Lemeshow 1989).

We used analysis of variance (ANOVA) to assess if the duration of time or distance that an owl was displaced differed among treatments and our control. We $\log_e(x + 0.1)$ transformed distance displaced. When the ANOVA indicated a $P<0.1$ difference among treatments, we used Tukey-Kramer HSD multiple comparison tests based on alpha = 0.05 to determine which treatments differed between each other or the control.

We also conducted a post-hoc analysis to assess if car color had a differential affect on the distance or time an owl was displaced by a car survey pass. We $\log_e(x + 0.1)$ transformed both variables.

All statistical analyses were performed using Program JMP 7.0.1 (SAS Institute, Inc., Cary, N.C.).

RESULTS

The probability that an owl being displaced during a survey differed among survey methods (whole model test: $\chi^2_4 = 82.2$, $P<0.0001$). The model performed fairly well at predicting when an owl would be displaced (area under the ROC curve = 0.74). Odds ratios indicated that, compared to the control group, an owl was 5 times more likely to be displaced by a passing survey car, 15 times more likely to be displaced by a walking surveyor, 16 times more likely to be displaced by a single car survey stop, and 27 times more likely to be displaced by a double car survey stop. A double car survey stop was 1.7 times more likely to displace an owl than a single car survey stop, a single car survey stop and walking surveyor were equivalent, but 3 times more likely to displace an owl than a passing survey car. Raw data for the proportion of owls displaced during each treatment are shown in Figure 3.1.

The time an owl was displaced differed between survey methods ($F_{4,390}=10.84$, $P<0.0001$), with owls responding to the control and car pass equally and at a shorter duration than that due to the remaining 3 survey methods that involved the presence of a surveyor (Tukey-Kramer HSD, $P<0.05$; Figure 3.2).

The distance an owl was displaced also differed between one or more treatments ($F_{4,390}=19.63$, $P<0.0001$), with owls responding to the control and car pass equally, but at a shorter distance than that moved in response to the remaining 3 survey methods (Tukey-Kramer HSD, $P<0.05$, Figure 3.2).

Car color did not have a differential affect on the time or distance an owl was displaced ($F_{4,74} = 2.26$, $P = 0.07$, $F_{4,74} = 2.41$, $P = 0.06$, with Tukey-Kramer HSD not detecting any differences at $P<0.05$).

CONCLUSIONS AND RECOMMENDATIONS

Compared to the control and car pass, the presence of a surveyor outside of a vehicle was the common factor among the 3 survey methods that led to significant increases in the

probability of owls being displaced as well as the distance traveled and time spent while displaced. Double car stops increased the probability that owls would be displaced, as well as the median distance traveled by the displaced owl (although the latter was not a statistically detectable difference due to high levels of variation). Surveys based on the car pass method could minimize disturbance and decrease bias associated with accidental double counting of due to movements, however, accurately recording an owl's location and surroundings from inside of the vehicle would be problematic. We recommend single car stops for conducting population surveys across the HCP Study Area because they are more efficient than walking and may reduce short-term responses compared to double car stops, which may help in minimizing bias associated with double counting.

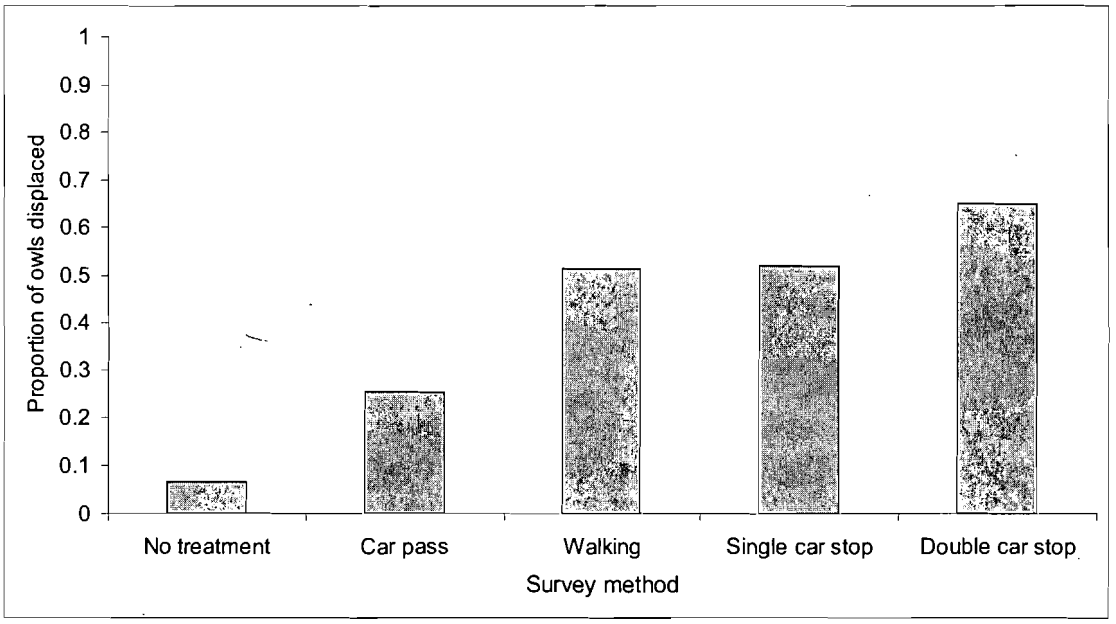


Figure 3.1. Proportion of owls displaced from a perch <20 minutes after a survey method was applied during the prehatch stage of the breeding cycle; no treatment represented an experimental control, Imperial Valley, California 2008.

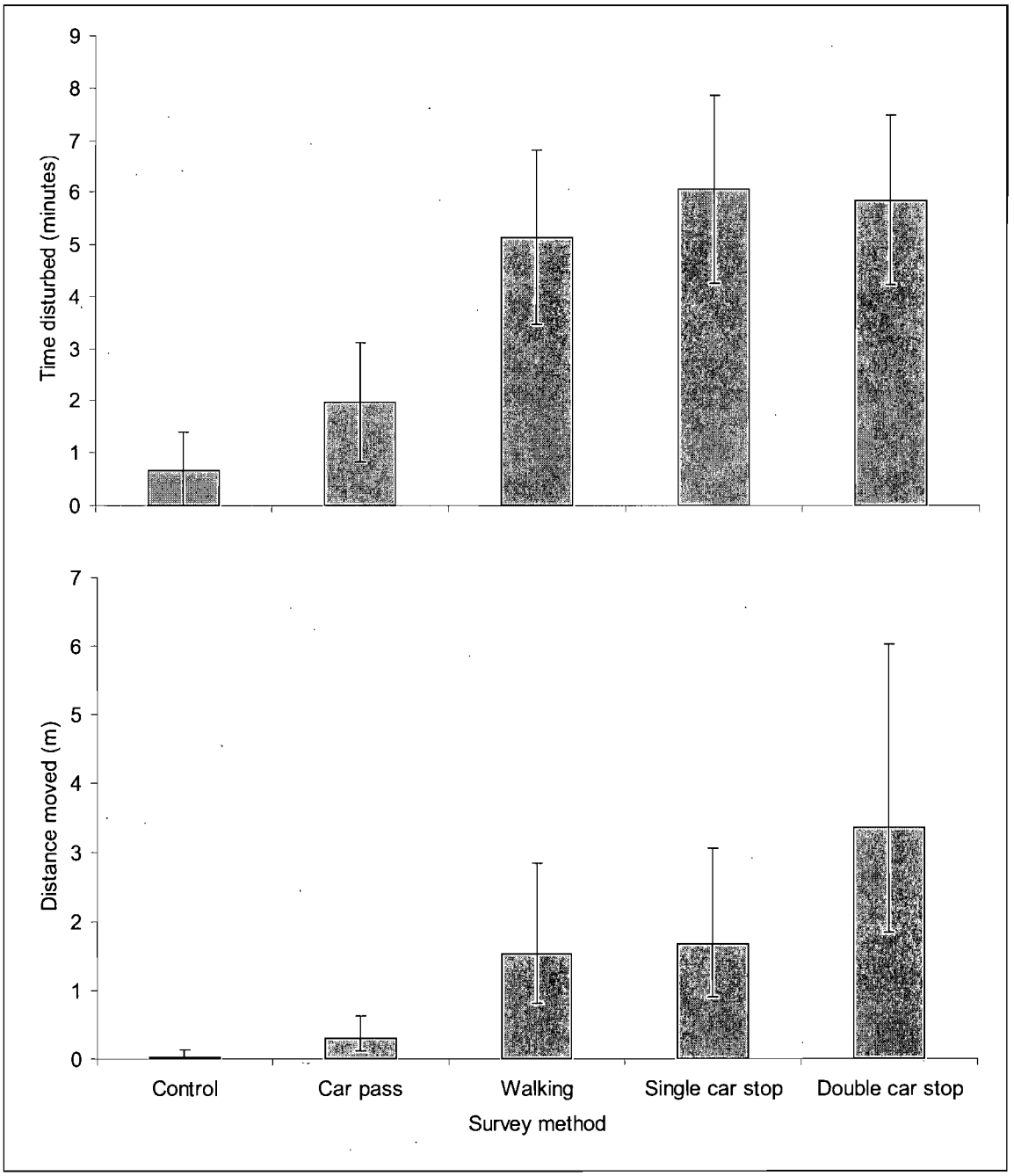


Figure 3.2. Average time and median distance that owls were displaced by a survey method during the prehatch stage of the breeding cycle, Imperial Valley, California 2008. Vertical bars are 95% confidence intervals.

Chapter 4

SINGLE VERSUS DOUBLE SURVEY PASSES

JEFFREY A. MANNING

ABSTRACT. Information on the reliability of surveys conducted from single versus double survey passes can aid in making decisions that balance cost and accuracy of population estimates. In response to Amendment 5, I present the results from a study that compared estimated population sizes, magnitudes of bias, and levels of precision between single and double pass surveys along water conveyance structures containing a known number of active Burrowing Owl territories in the HCP Study Area. I showed evidence that there is no appreciable difference in detection rates or abundance estimates between 1 versus 2 survey passes. Because the cost of 2 survey passes would be nearly twice that of a single survey pass and restricted access to both sides of numerous drains and canals across the HCP Study Area would lead to unequal levels of effort when using the 2 survey pass method, which would introduce an unknown level of error in population estimates that may fluctuate between grid cells and years based on access and maintenance, I concluded that 1 survey pass provides an adequate and consistent method of surveying for male Burrowing Owl territories in the HCP Study Area.

INTRODUCTION

The IT requested that we evaluate the differential effects of single versus double survey passes on bias and precision of population estimates. In chapter 3, Manning and Kaler compared short-term behavioral responses by Burrowing Owls to 4 methods of surveying owls and an experimental control. In that study, we used double car stops along the same side of the drain as a surrogate for two survey passes where each would occur on either side. We found that although not statistically significant, double car stops at Burrowing Owls during the prehatch stage of the breeding cycle were shown to increase the probability and distance of displacement. We concluded that these increases could lead to accidental double counting of owls, which can bias population estimates high. In this study, single and double pass surveys along water conveyance structures containing a known number of active Burrowing Owl territories were conducted during the prehatch stage of the breeding cycle. From these data, I computed population estimates, magnitude of bias, and level of precision between these 2 survey methods.

METHODS

I randomly selected 4 irrigation drains (Rice, Central, Strout, and Date drains) in the southern portion of the HCP Study Area (Figure 4.1), and conducted point-coordinate capture-recapture surveys (see chapter 7 for detailed description of survey method) along a randomly selected 4-km length (route) of IID rights-of-way along each drain. I focused on that portion of the HCP Study Area due to logistical constraints, but believe that the results can be inferred to irrigation drains throughout the HCP Study Area because

environmental conditions, habitat characteristics, and owl numbers and distribution appear to be similar along drains in the north and south portions. Surveys were completed during the prehatch stage of the breeding cycle, between 26 April and 2 May, 2007, which lies within the period previously recommended for conducting population surveys.

Each drain route was surveyed on both sides along IID rights-of-way in opposing directions 3 times (occasions), following the survey methods described in chapter 7 along the same path. When a survey was completed on one side, the surveyors waited >15 minutes at the end of the survey route to allow owls to resume normal behaviors and perching that may have been disturbed by the first survey pass. This produced the first, third, and fifth survey passes in the same direction on the same side of a drain, and the second, fourth, and sixth passes on the opposing side and direction of the corresponding drain.

I combined the first, third, and fifth survey pass data (which were in the same direction) along a route, and considered these to represent 3 single pass survey occasions. I further combined the first and second passes that were in opposing directions along each route, and considered these as the first double pass survey occasion, and applied this to the remaining 2 groups of opposing passes to produce the 2nd and 3rd double pass survey occasions. These groupings enabled me to develop capture-recapture encounter histories from single pass surveys and separately for double pass surveys along the same randomly selected drains.

I used estimated the abundance of owls from single and double pass surveys in each drain separately. I fit 2 maximum likelihood, multinomial, closed-population models to these data with a sin link function using Program MARK (Otis et al. 1978, White et al. 1982, Cooch 1999, White and Burnham 1999). One assumed constant detection probabilities and the other assumed that detection varied among survey occasions. I applied an information theoretic framework (Burnham and Anderson 2002) to select the best model for each drain separately because the goal was to obtain the most reliable estimates of abundance.

Additionally, I pooled the 4 routes into 16 km of surveyed irrigation drain, and pooled the resulting encounter histories into 2 groups based on single and double pass surveys. I fit maximum likelihood, multinomial, closed-population models with a sin link function available in Program MARK (Otis et al. 1978, White et al. 1982, Cooch 1999, White and Burnham 1999) to these data, and applied an information theoretic framework (Burnham and Anderson 2002) to assessing differences between single and double pass surveys. I developed an *a priori* set of multiple working hypotheses that involved similarities and differences in detection probabilities and/or abundances between single and double pass surveys, and constructed a separate model for each hypothesis. I used Akaike's Information Criterion adjusted for small samples (AIC_c) with a cutoff of 2.0 and the principle of parsimony to determine the best model (Akaike 1973, Burnham and Anderson 2002). I assessed the lack-of-fit of the best model here and in the prior closed-population analyses to the data by examining a plot of its deviance residuals. A

symmetric and narrow pattern of deviance residuals close to zero would suggest a good fit to the data, whereas a wide pattern around zero would suggest poor fit due to extra-binomial variation.

To estimate the true number of male Burrowing Owl territories along the survey routes, I used all nest locations from the surveys that were located >40 m apart. I chose this distance because owls occupy non-overlapping diurnal home ranges and spend >80% of the time within 40 m of their nest (as shown in Chapter 2). I assumed that nest locations closer together than 40 m represented additional burrows in a complex occupied by a single pair.

RESULTS

Based on our count of owl nests that were >40m apart, there were a total of 57 male Burrowing Owl territories in the 4 drain routes. A single survey pass produced estimates of abundance for each drain route that was 5 to 25% biased below the true number of territories believed to be present (Figure 4.2), whereas the bias associated with 2 survey passes ranged from -7 to 12% (Figure 4.2). Population estimates from 2 survey passes produced less bias in each of the 4 drain routes, the single survey pass was consistently below the true number, and both survey methods were similar in their precision (i.e., the range in bias for the 1 survey pass was 20% and that of 2 survey passes was 19%).

The comparison of multiple closed-population models fit to the larger dataset that was created by pooling the 4 replicate drain routes led to 3 competing models that best explained the variation in the data ($\Delta AIC_c<2.0$; Table 4.1). Based on the principle of parsimony, the simplest of those 3 models [p=c(.) N(.)] represented the hypothesis that capture and recapture probabilities did not differ between 1 and 2 survey passes and the estimated abundances also did not differ between them. Based on AIC_c weights, that model had the highest level of support, and there was 50% more evidence for it being the best model over replicated datasets compared to the next best model (Table 4.1). This model fit the data well (deviance residuals followed a narrow and symmetric pattern surrounding zero), and the model estimated capture and recapture probability for both methods to be 0.77 (SE = 0.03) and the abundance estimates were 49 (95% CI: 48-56) for 1 survey pass and 55 (95% CI: 55-59) for 2 survey passes.

CONCLUSIONS AND RECOMMENDATIONS

The comparison of multiple working hypotheses with the information theoretic approach over the combined dataset provided evidence that there is no appreciable difference in detection rates or abundance estimates between 1 versus 2 survey passes. When the data was analyzed individually for each survey route, 2 survey passes produced less bias in estimated abundance for each of the 4 drain routes. The 2 survey pass method produced estimates that were sometimes positively and sometimes negatively biased, while the single survey pass was consistently below the true number when drains were analyzed surveyed.

One explanation for the difference in bias between the 2 levels of survey effort when examining the data at the level of short drain routes may be due to the poor performance of capture-recapture models with small sample sizes like those present in each drain route. In this situation, the estimator did not correct for visibility bias efficiently with the small observed samples to adequately correct estimated abundance. This is especially important for the single pass data because the assumption is that all territories are not counted in every pass, but that this will be corrected for by the capture-recapture model. For the 2 survey pass method, the number of counted territories should be closer to the true number present, and the capture-recapture model should not inflate the estimate as much. The analysis with the pooled data is likely more representative of the results that may be obtained when sampling 3x3 km grid cells or larger areas in the HCP Study Area. The similar levels of precision from 1 and 2 survey passes suggests that both may be adequate for monitoring changes in the size of the population or relative differences among grid cells in the HCP Study Area.

Some other differences between conducting 1 and 2 survey passes that were not examined here include cost and consistent levels of effort across the HCP Study Area in order to obtain comparable estimates of abundance among local areas or grid cells. Cost would approximately double if two survey passes were conducted instead of one. Additionally, restricted access to both sides of numerous drains and canals across the HCP Study Area would lead to unequal levels of effort. This would introduce an unknown level of error in population estimates that may fluctuate between grid cells and years based on access and maintenance. For these reasons, it is reasonable to conclude that 1 survey pass provides an adequate and consistent method of surveying for male Burrowing Owl territories in the HCP Study Area during the prehatch stage of the breeding cycle. Although this method may slightly underestimate the number of territories along large drains, this bias should be small and consistent between years, allowing for accurate detection of changes in population size.

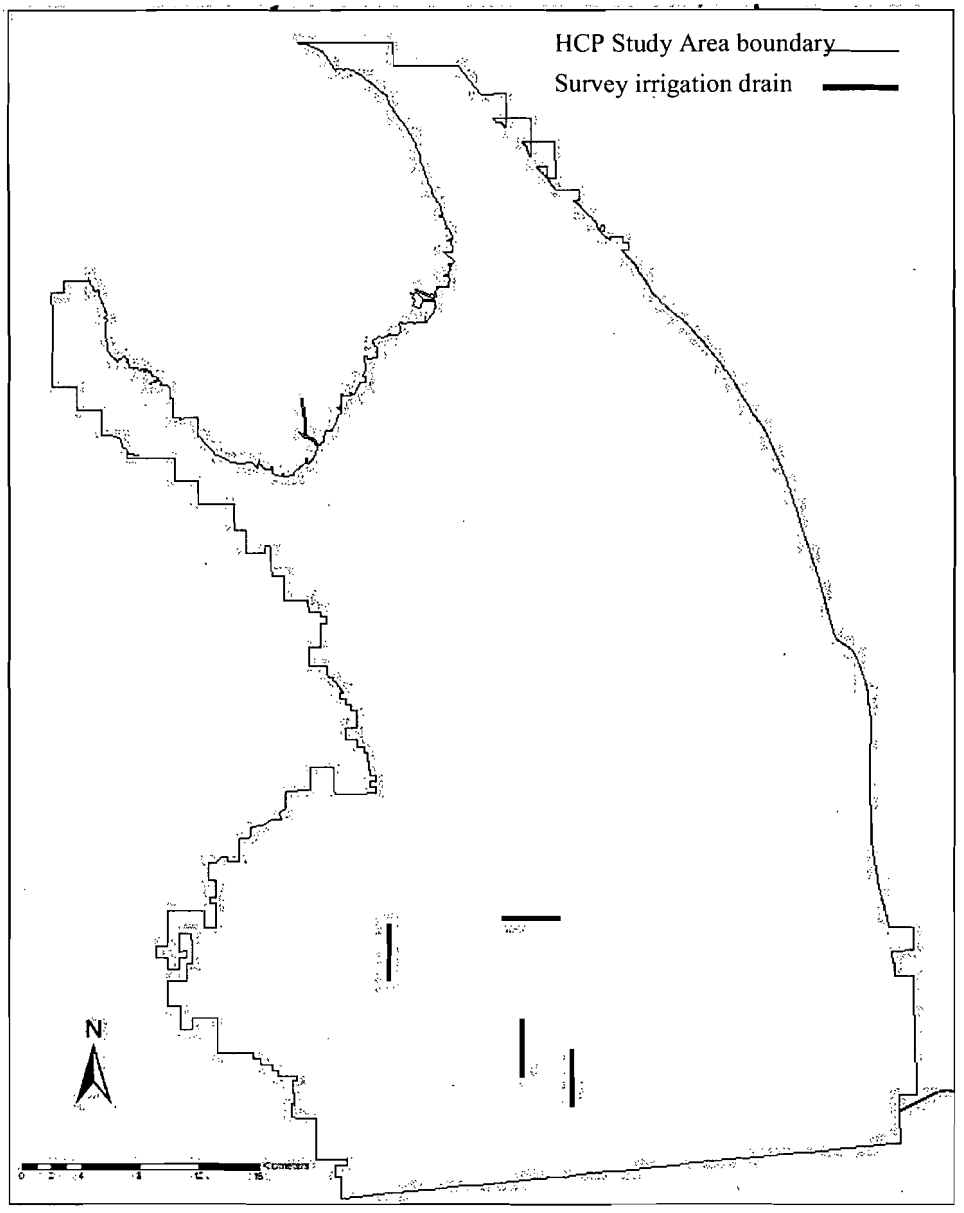


Figure 4.1. Locations of four randomly 4-Km lengths of irrigation drain where point-coordinate capture-recapture surveys were conducted for male Burrowing Owl territories using 1 and 2 survey passes in the HCP Study Area, Imperial County, California, 26 April - 3 May, 2007.

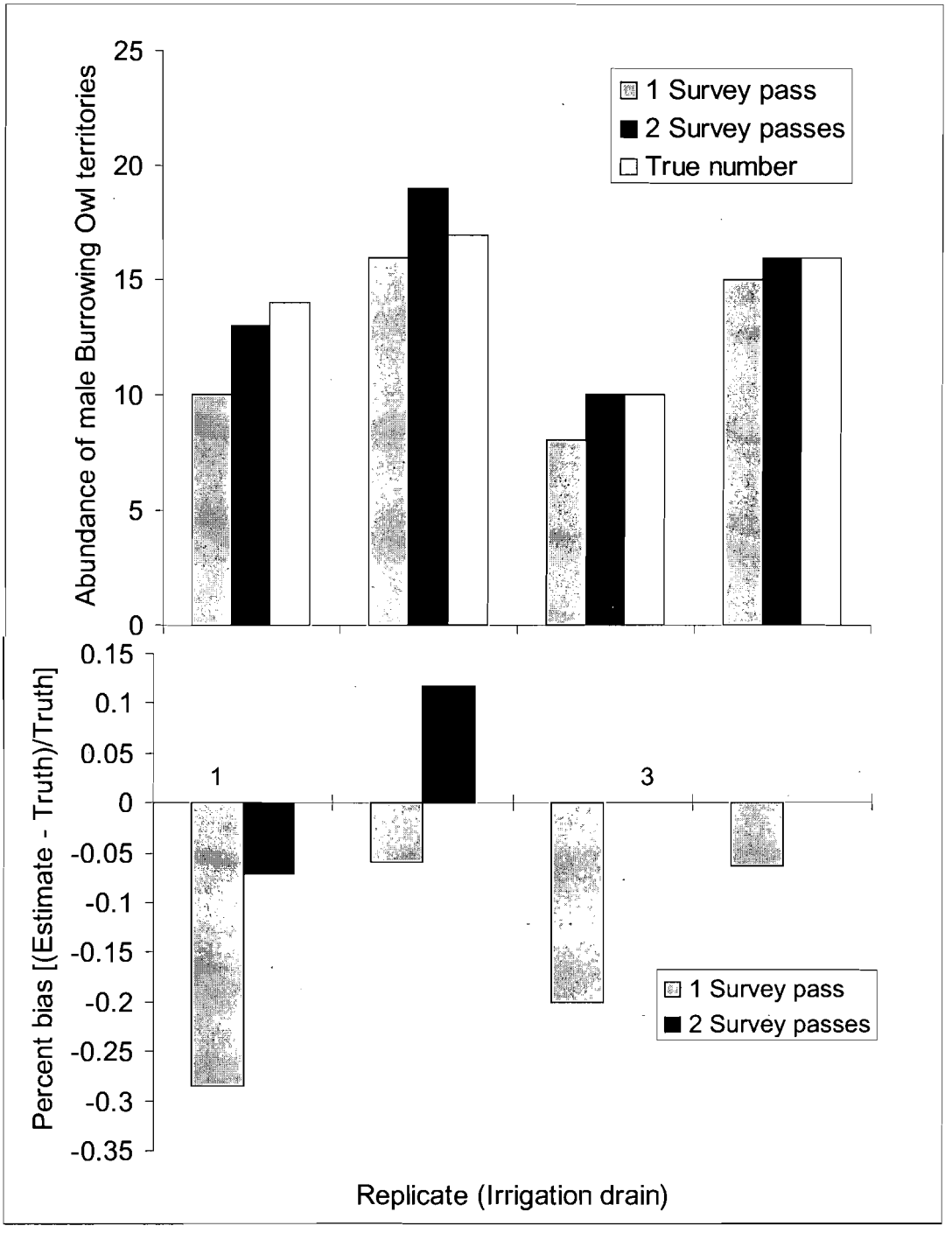


Figure 4.2. Abundance (A) and associated percent bias (B) of estimated male Burrowing Owl territories from 1 or 2 survey passes along 4 randomly selected 4-Km lengths of irrigation drain in the HCP Study Area, Imperial County, California, 26 April - 3 May, 2007.

Table 4.1. Maximum likelihood closed-population models applied to point-coordinate capture-recapture data of male Burrowing Owl territory encounter histories to assess differences in detection [capture (p) and recapture (c)] probabilities as well as abundance between single and double survey passes during the prehatch stage of the breeding cycle in the HCP Study Area, Imperial County, California, 26 April - 2 May, 2007. Models were constructed with the sin link function in Program MARK, and model syntax followed Otis et al. (1973) and White and Burnham (1999).

Model	ΔAICc	AICc Weight	Likelihood	No. of Estimated Parameters	Deviance
N(.) p=c[1](.)	0.00	0.31	1.00	2	21.70
N(survey type) p=c(survey type)	0.72	0.22	0.70	3	20.38
N(.) p=c(survey type)	0.84	0.21	0.66	3	20.50
N(survey type) p=c(.)	2.03	0.11	0.36	3	21.69
N(.) p=c(t)	2.36	0.10	0.31	4	19.97
N(survey type) p=c(t)	4.42	0.03	0.11	5	19.96
N(survey type) p=c(survey type × t)	7.12	0.01	0.03	7	18.49
N(.) p=c(survey type × t)	7.23	0.01	0.03	7	18.60

[1] capture and recapture probabilities were modeled to be equal

Chapter 5

POINT-COORDINATE CAPTURE-RECAPTURE TECHNIQUE TO PRODUCE UNBIASED CLOSED CAPTURE-RECAPTURE ESTIMATES OF MALE BURROWING OWL TERRITORY ABUNDNANCE

JEFFREY A. MANNING AND CAREN S. GOLDBERG

ABSTRACT. Due to the extent of the distribution and high abundance of Burrowing Owls in the HCP Study Area, an efficient and reliable method of surveying is needed. Here, we address Amendment 2, and present the results from developing a closed-population capture-recapture survey technique that relied on a swift recording of each Burrowing Owl's location. We developed this method to provide a cost effective method of surveying owls in the HCP Study Area, where other methods of surveying could be costly or hampered by the high density of owls. We formalized, tested, and validated the technique, showing that it produced unbiased estimates of male Burrowing Owl territory abundance.

INTRODUCTION

Many methods used to obtain abundance estimates for wildlife populations involve some form of closed-population capture-recapture sampling (Williams et al. 2002). Capture-recapture methods stem from a strong statistical and theoretical foundation and long history involving mobile animals (Petersen 1896, Otis et al. 1978, Williams et al. 2002). The general principle of capture-recapture methods is to uniquely tag individuals in a first capture occasion and record the proportion of tagged individuals in subsequent recapture occasions, with information about the detectability of organisms obtained from the recapture information of individuals (Williams et al. 2002). However, the intensive effort required to capture and tag individual animals (e.g., see Seber 1982:93 for a list of methods) can render capture-recapture methods cost prohibitive in some cases (Otis et al. 1978, Pollock et al. 1990, Petitt and Valiere 2006). Moreover, these techniques may be impractical in instances where tagging is difficult or when the population is widespread or abundance spatially variable, and the disturbance of capture activities may be incompatible with conservation strategies for sensitive species (Royle and Nichols 2003, Royle 2004). Alternatives to physically capturing and tagging animals in capture-recapture studies may reduce effort and cost, thus enabling conservation and management programs, such as that proposed for the Burrowing Owl in the HCP Study Area, to conduct annual population monitoring.

As an alternative to physically marking Burrowing Owls in the HCP Study Area, we proposed collecting point coordinates of burrowing owls during multiple occasions to generate capture-recapture encounter histories (Section 5.2 of Qualification Request #531: Final Detailed Study Approach for a Burrowing Owl Population Study). This novel approach does not require that individual owls be physically marked, but rather their point coordinates recorded and used to generate 'new' captures and recaptures. A

primary concern with this technique is the effect of misidentifying individual owls because owls move within their home ranges among survey occasions. Here, misidentification consists of 2 types of error: intrusion by neighbors and misidentifying recaptures as 'new' individuals. However, Kendall (1999) found that closed-population methods are robust to completely random movement by individuals in and out of a study area, and that estimates remain unbiased under this scenario. Equivalently, if the types of misidentification associated with using point coordinates are random, unbiased estimates of burrowing owl abundance may be attainable from encounter histories generated from point-coordinate-based survey data in the HCP Study Area.

We assessed the effects of these sources of misidentification on population estimates obtained from capture-recapture analyses computed from point-coordinate-based encounter histories. The objective of this study was to assess the probability that a 'recapture' was recorded when a pair was not seen in the buffer and effects of buffer size, detection probabilities, and owl density on the bias and precision of population estimates computed using encounter histories developed from point-coordinate data. We were particularly interested in identifying a standardized buffer width that could be used to surround each point coordinate to generate capture-recapture encounter histories.

We thank Dr. Bryan Manly (West, Inc., 2003 Central Avenue, Cheyenne, WY 82001, bmanly@west-inc.com) for his review and suggestions to perform simulations, which greatly improved the analysis. He also provided a letter to Brad Norling of the Imperial Irrigation District, dated August 22, 2007, concluding that the recommendations provided in this chapter represent the best approach.

METHODS

1. Collected field data between April 11-May 2, 2007
2. 40 individual burrowing owls from 40 breeding territories (Figure 5.1).
3. Individuals were believed to be males because they were visible much of the time during the peak period when females were anticipated to be on eggs.
4. Leg-banded most, but not all, individuals with unique numbers before April 11.
5. Conducted 13-hr continuous observations (0600-1900)/individual.
6. Recorded point coordinates of owl perch locations every 15 minutes when visible (n=1,400) using a Trimble GeoXM GPS, rangefinder, and compass with <3m accuracy. The flat agricultural landscape enabled us to maintain sight of owls even when they traveled far distances.
7. Considered the burrow entrance with the greatest amount of sign (e.g., excrement, pellets, feathers, tracks) in each territory to be the primary burrow entrance, recorded its GPS location, and used ArcGIS 9.2 (ESRI, Redlands, CA) to measure the distance between each owl's location and its primary nest burrow entrance.
8. Computed 95% fixed kernel home range utilization distributions for each owl, based on likelihood cross validation smoothing because likelihood cross-validation has been shown to be a better procedure for small sample sizes and for obtaining more accurate estimates in high use areas then other methods (Horne

and Garton 2006). This was intended to assess the level of overlap among neighboring owls.

9. Created 15 Monte Carlo datasets (each containing 4 survey occasions) by bootstrapping the original field sample to mimic our actual 4-occasion survey effort across the HCP. We decided on using 15 subsamples rather than the originally proposed 30 because variances with 15 were sufficiently small. We applied a constant detection probability (0.7), based on the average probability during diurnal periods (see Chapter 2), by randomly removing 12 of the 40 observations from each occasion.
10. These bootstrapped data were used to create capture-recapture encounter histories by buffering point coordinates with various buffer radii, generating centroids for each individual, and using the buffer radius specified to assign the latter occasion's point coordinates as existing or new individuals by the following rules:
    a. Owl point coordinate locations recorded on occasion 1 were considered as new individuals.
    b. Owl locations from occasion 2 were determined to be recaptures if they were the closest location of a location in occasion 1 and buffers from each location overlapped. All other owls from occasion 2 were considered as new individuals.
    c. We computed a center location (centroid) for owls that were observed in both occasions.
    d. Owl locations from occasion 3 were determined to be recaptures if they were the closest location to a centroid or a location from occasions 1 or 2 that were captured only once and buffers from the previous and new location overlapped. All other owls were considered to be new individuals.
    e. We computed a centroid for all owls that were captured in 2 or more occasions.
    f. Owl locations from occasion 4 were determined to be recaptures if they were the closest location to a centroid or location from occasions 1, 2, or 3 that were captured only once and buffers from the previous and new location overlapped. All other owls were considered to be new individuals.
11. Calculated the probability that encounter histories would contain misidentified owls (owls identified as their neighbor due to their location and neighbor's non-detection).
12. Computed closed-population, capture-recapture estimates of population size ($\hat{N}$) for each bootstrapped sample using the standard model structure [N(subsample) p=c(.)]; models were developed using the closed captured model with the sin link function available in Program MARK (Cooch 1999, White and Burnham 1999).
13. Computed mean estimates of population size and 95% confidence intervals for each buffer size and compared them to true (known) numbers.
14. Conducted additional simulations to test for the effects of detection probability on population estimates given the optimal buffer size.
15. Tested the effects of owl density on point-coordinate capture-recapture population estimation using additional Monte Carlo simulations with the same parameters as

for the full dataset for 2 survey routes of different densities (7 owls/km and 15 owls/km).

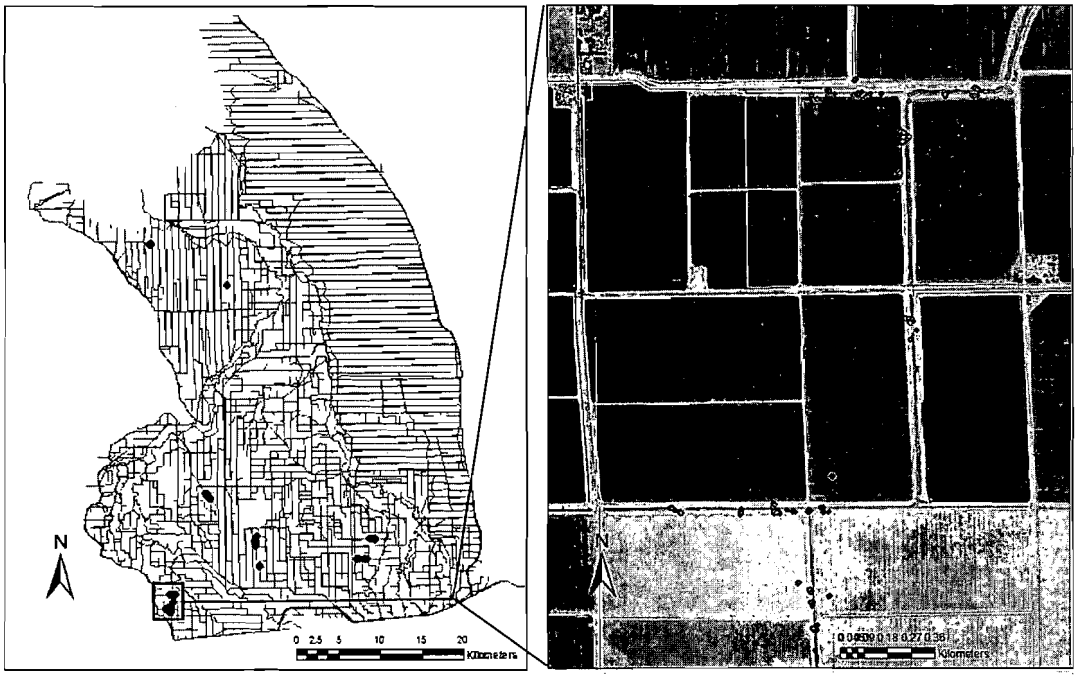


Figure 5.1. Point coordinate locations (n=1,400) of 40 individual burrowing owls at 8 randomly selected locations, Imperial Valley, California 2007.

RESULTS

The mean maximum distance between all locations of each owl was 89.2 m (95% CI: 66.9 to 111.5 m), the mean maximum distance moved (MMDM) from a nest was 58.4 m (95% CI: 46.2 to 70.5), and densities ranged from 7-15 nests/km.

Likelihood Cross Validation Fixed Kernel Home Range Sizes of Burrowing Owls and Volume of Overlap by Neighboring Owls

We used the 15-minute diurnal locations to compute fixed kernel home ranges, from which we assessed volume of home range overlap for neighboring owls. We found that on average, the amount of overlap that occurs between neighboring territorial Burrowing Owls is negligible (Mean = 0.8%, 95% CI = 0-1.9%). Such a low level of overlap suggests that misidentification of neighboring owls while using the point-coordinate-based closed capture-recapture approach used here may not occur often in the Imperial Valley agricultural matrix.

However, portioning the 2 sources of misidentification out into its constituent parts showed that the probability that a correct owl (i.e., the owl actually occupying the territory being sampled) is present for detection rapidly decreased with distance from its nest burrow, and that probability approximated zero at 110 m from the burrow (Figure

5.2). As expected, the probability that a wrong owl (i.e., neighboring owl) is present for detection in the territory being sampled increases with distance from the correct owl's nest (Figure 5.2). In other words, the closer an owl was to an active burrow when detected, the higher the probability that it was the correct owl and the lower the probability that the owl was the wrong owl, as suggested by the utilization distributions presented in chapter 2.

This expected interaction between these 2 sources of misidentification with buffered point-coordinates was the impetus for the following bootstrapping analyses.

Probability that a Recapture is Recorded when the Breeding Pair is Unavailable for Detection in the Buffer

Given a constant buffer radius approximately equal to the MMDM (55 m), a constant detection probability (0.7), 4 encounter occasions, and 40 original owls, there were 48 instances in each Monte Carlo simulation where a breeding pair was unavailable for detection.

Monte Carlo simulations indicate that the mean probability that a 'recapture' would be recorded when a pair is not available for detection, given the simulation conditions, is 0.085 (N = 15, SE = 1.1). This occurred when the correct owl was not observed, but a neighboring owl was falsely identified as the missing owl. Overall, for a survey under these conditions, the probability of this form of misidentification occurring is 0.025 (N = 15, SE = 0.3) for each observation.

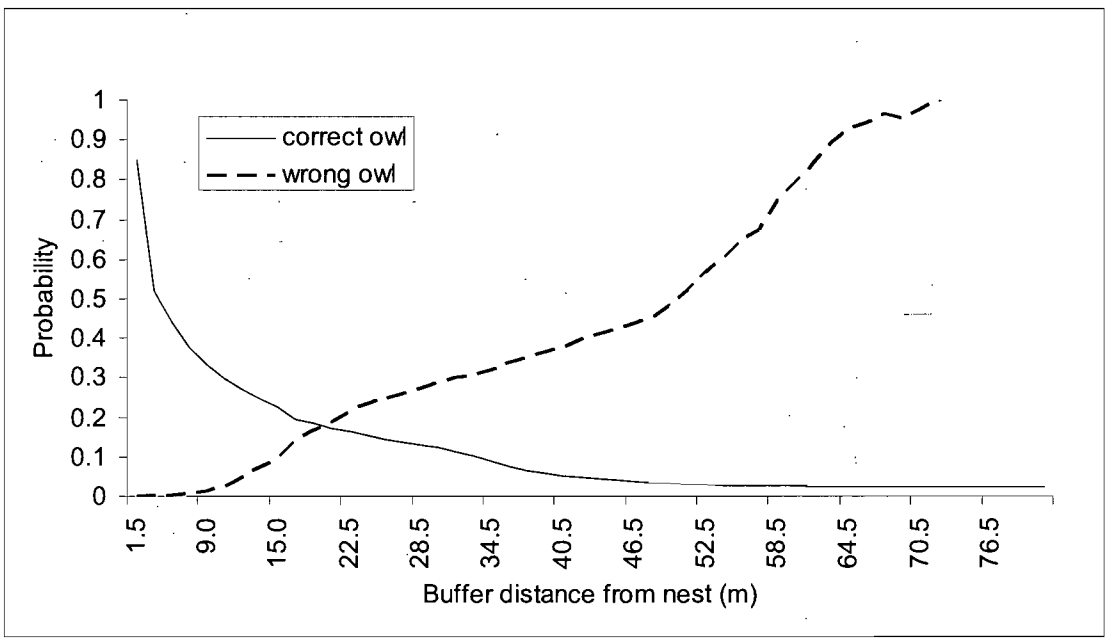


Figure 5.2. Probabilities that the correct and wrong male Burrowing Owls are present and available for detection at increasing distance from the correct owl's nest, Imperial Valley, California, April 2007.

Effects of Buffer Size on Population Estimates

Monte Carlo simulations with a constant detection probability of 0.7 indicated that the buffer radius that produced highly precise and unbiased population estimates was 55 m, approximately equal to the MMDM (Figure 5.3). These results also suggest that the effect of misidentification of individual owls as neighbors is minimal on population estimates relative to effects of misidentifying a recapture as a 'new' individual.

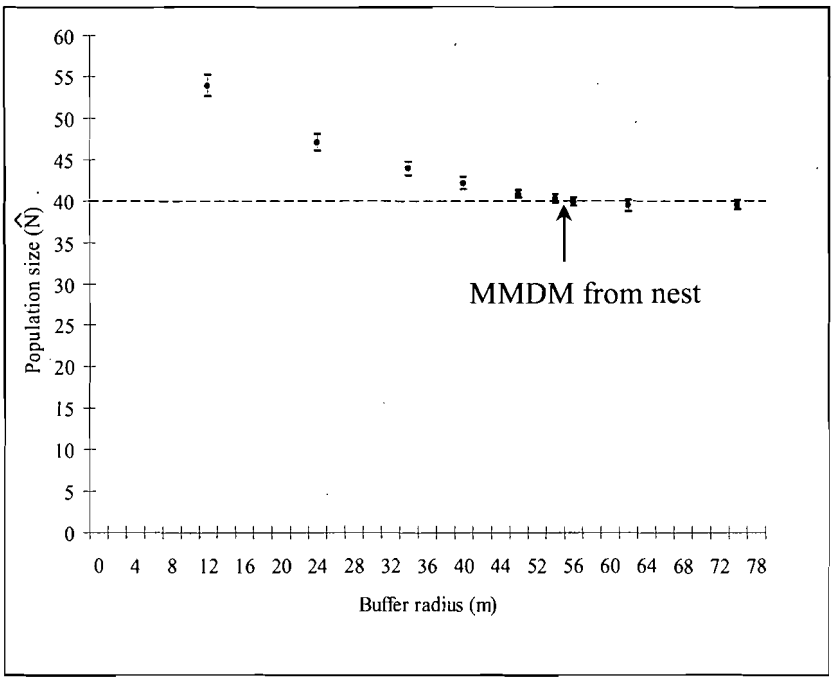


Figure 5.3. Effects of buffer size (radius) surrounding burrowing owl capture-recapture point coordinates on closed-population estimates, Imperial Valley, California. Dotted line represents true N. Vertical bars are 95% CI. Estimates are from closed-capture models [N(rep) p(.)=c(.)]; data bootstrapped from 15-min locations (with p-hat=0.7) recorded consecutively from 0600-1900 for 40 male breeding burrowing owls from April-May, 2007.

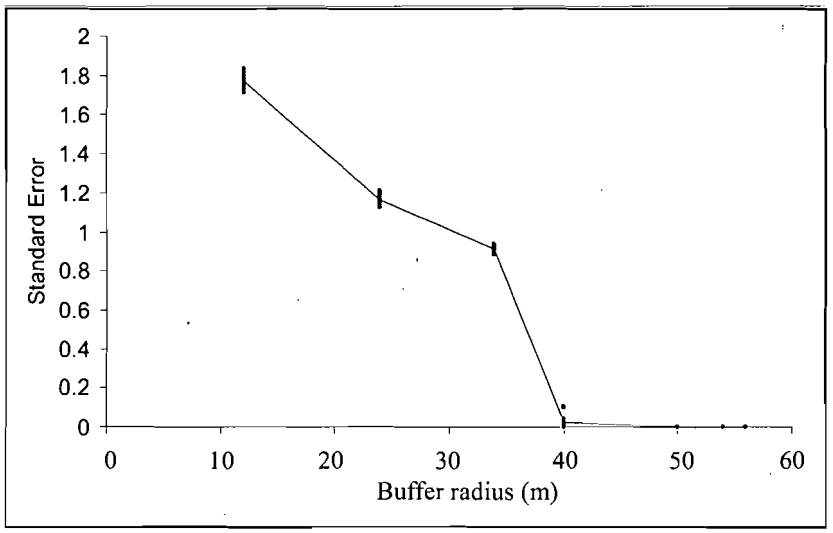


Figure 5.4. Effects of buffer size (radius) surrounding capture-recapture point coordinates of male Burrowing Owls on the standard error of closed-population estimates, Imperial Valley, California. Vertical bars are 95% CI. Estimates are from closed-capture models [N(rep) p(.)=c(.)]; data bootstrapped from 15-min locations (with p-hat=0.7) recorded

Effects of Detection Probabilities on Population Estimates

We found that the high level of accuracy obtained by buffering point coordinates with a buffer radius equal to the MMDM was robust to varying detection probabilities between 0.6 and 0.9, yielding relatively unbiased, precise estimates of male Burrowing Owl territory abundance (Figure 5.5). Detection probabilities near 0.6 may produce slightly biased low (~1%) population estimates and 0.9 slightly biased high (~1%) from the true number, but the true number fell within all 95% CIs (Figure 5.5).

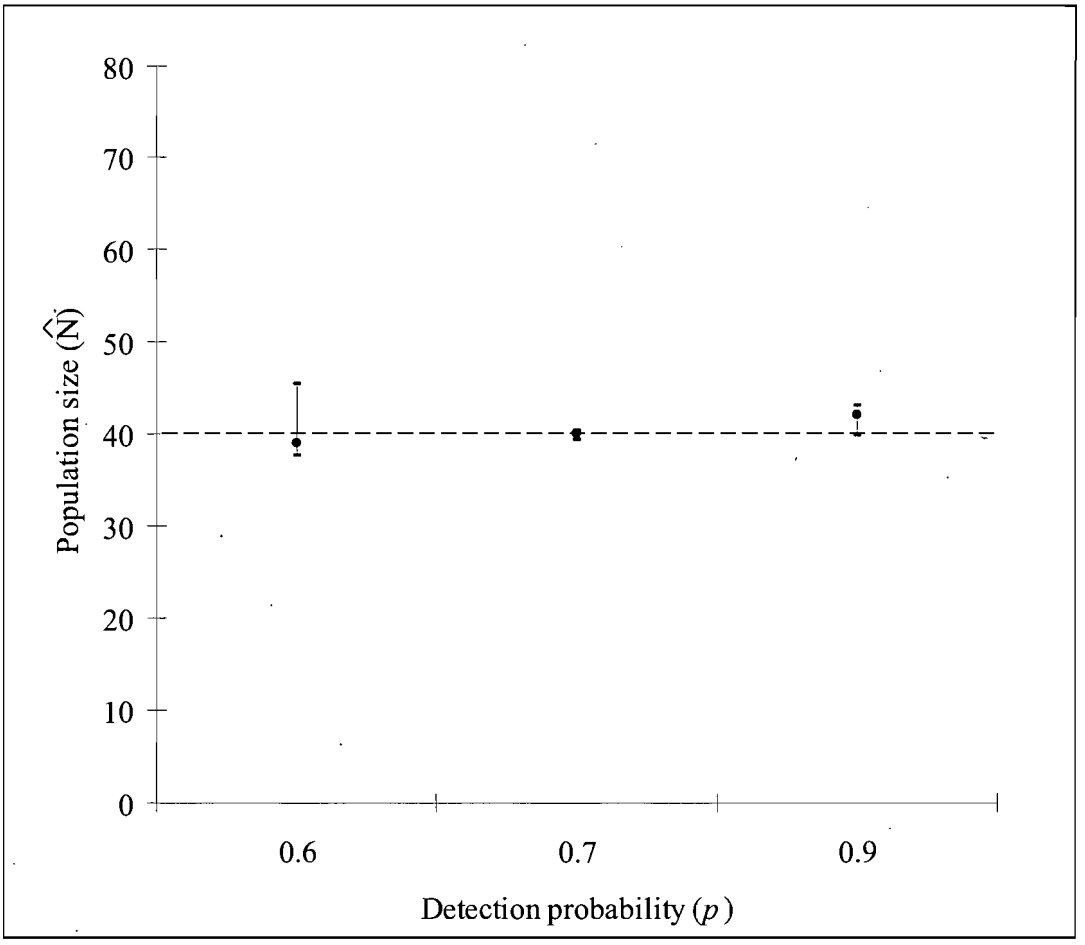


Figure 5.5. Effects of detection probabilities on burrowing owl population estimates based on a 55 m buffer surrounding capture-recapture point coordinates, Imperial County, California 2007. Dotted line represents true N. Vertical bars are 95% CI.

Effects of Density on Population Estimates

The following results are based on a fixed buffer = 55 m and a constant detection probability (0.7) and used a Monte Carlo simulation as above to create datasets representing 4 capture survey occasions along these 2 routes.

Low density (6 adjacent owls where the linear density = 7 owls/km)

Mean $\hat{N}$ = 6.1, 95% CI: 5.8 to 6.5

This $\hat{N}$ approximates the true N = 6 with reasonably good precision that encompasses the true N.

High density (7 neighboring owls where the linear density = 15 owls/km)

Mean $\hat{N}$ = 7.1, 95% CI: 6.8 to 7.5

This $\hat{N}$ approximates the true N = 7 with reasonably good precision that encompasses the true N.

CONCLUSIONS AND RECOMMENDATIONS

We found that buffering burrowing owl point coordinates with a 55 m radius circle yielded relatively precise, unbiased estimates of burrowing owl abundance that we believe are adequate for estimating annual burrowing owl abundances across the HCP on an annual basis. The 55 m radius circle essentially enabled us to identify locations from subsequent survey occasions that were the closest within 110 m from previous locations as recaptures, which corroborates with the results presented in figures 2.3 and 5.2. Our results suggest that the misidentification errors due to using point-coordinate-based encounter histories in capture-recapture analyses are random and therefore do not introduce bias into estimates of population abundance (Kendall 1999). This is because when a neighboring owl is misidentified as a recapture in its neighbor's buffer when its neighbor is undetected, the misidentified pair receives a 'zero' in its encounter history, thereby maintaining the constant probability of detection for the cohort in that occasion.

This technique produces encounter histories that provide unbiased, precise population estimates from currently available capture-recapture models. Consequently, in combination with the low level of measurement error associated with acquiring point-coordinate locations (see Appendix II for details), we believe this approach is well suited for population-level analyses. However, use of point coordinates recorded by observing vagile species like owls leads to shifting of encounters among neighboring individuals in an occasion, which can lead to unreliable estimates of detection probabilities at the level of individual animals. Thus, we (and Dr. Bryan Manly, personal communication) do not advocate the use of point coordinate capture-recapture encounter histories for estimating parameters in individual-based analyses (e.g., use of individual covariates).

This point coordinate technique is suitable for surveying Burrowing Owls in the HCP because it:

1. produces: A. unbiased, precise estimates of abundance,

2. is robust to: A. variable probabilities of detection among encounter histories and B. variable densities, and

3. assumes: A. high probabilities of detection (>0.6)

The Imperial Valley agricultural matrix supports conditions that meet these assumptions. Thus, we believe that the point-coordinate capture-recapture technique is an efficient technique to obtain unbiased estimates of male Burrowing Owl territory abundance in that area.

Chapter 6

NUMBER OF SURVEY OCCASIONS

JEFFREY A. MANNING AND CAREN S. GOLDBERG

ABSTRACT. Cost benefit information is always beneficial in designing population monitoring programs. We evaluated the minimum number capture-recapture survey occasions needed in the HCP Study Area to calculate accurate estimates of population size. We found clear evidence that a minimum of 3 survey occasions were necessary when using the point-coordinate capture-recapture technique to achieve an acceptable level of accuracy in estimating the abundance of male Burrowing Owl territories. Three survey occasions nearly doubled the precision of population estimates compared to using only 2 occasions, and a retrospective power analysis showed that ≥4 occasions provided little improvement over the 3, indicating that an increase in the number of surveys beyond 3 did not appreciably improve power, and doing so would only be at an unnecessary expense.

INTRODUCTION

To ensure accuracy of estimated owl abundances in the HCP Study Area while minimizing costs, it is essential that detection probabilities, level of effort, and sampling/analysis methods be carefully selected prior to starting the formal population-level study. To reduce cost while maintaining accuracy, it is important to determine the minimum amount of effort necessary to achieve an acceptable level of accuracy.

One type of field sampling effort associated with the approach we proposed for estimating abundance relates to the number of repeated surveys (occasions) needed to obtain accurate estimates of population size each year. As described in the original proposal, repeated survey occasions are a necessary part of the proposed closed population capture-recapture method. The original proposal called for 2 occasions. However, further insight into the existing literature on Burrowing Owls led to recommending alternatives to using only 2 occasions, as described in the letter from Bloom Biological Inc. to Bruce Wilcox dated February 24, 2006, one of which was the addition of a pilot study.

We conducted a pilot study of point-coordinate capture-recapture surveys of Burrowing Owls across approximately 412 randomly selected km of IID right-of-way in the HCP Study Area to assess the minimum number of sampling occasions required to obtain accurate estimates of population size. This was followed by prospective power analyses to elucidate the statistical power behind the minimum number of repeat sampling occasions that we identified. We assessed the accuracy of population estimates ($\hat{N}$) by their corresponding coefficients of variation ($CV(\hat{N})$). The $CV(\hat{N})$ reflects precision, and an acceptable level of precision for reliable scientific studies is considered to be 0.1 (White et al. 1982).

These initial analyses were based on 20-m buffer around each owl location to generate capture-recapture encounter histories, followed by fitting maximum-likelihood, closed-population models (Cooch and White 2006) to each capture-recapture encounter history dataset. These preliminary analyses led us to initially conclude that 4 capture-recapture survey occasions were necessary to achieve reasonably accurate estimates of male Burrowing Owl territory abundance. However, an independent peer reviewer raised several concerns regarding this buffer size, which instigated our development of the Monte Carlo simulations of the point-coordinate capture-recapture technique in 2008, as described in Chapter 5.

In order to determine the minimum number of repeat sampling occasions required to achieve accurate estimates of population size, in this chapter, we reanalyzed the 2006 data using the new analytical point-coordinate capture-recapture technique, with the mean maximum distance moved (55m) as the buffer radius (see Chapter 5 for details).

METHODS

Field Surveys

We conducted diurnal, capture-recapture surveys for Burrowing Owls from April 16-May 20, 2006 using the following detailed methods:

1. Randomly selected 64 replicate survey routes (each approximately 6.4 km in length; Figure 6.1).
2. Conducted surveys for approximately 1-hour in each replicate route at approximately the same time of day (between 0630-1830, excluding 1230-1330) for 6 consecutive days (occasions).
3. Used 1 vehicle/route (each having a driver and observer) to conduct visual surveys at 7 mph. Vehicle was positioned so observer was closest to drain/canal, observer surveyed passenger side of vehicle, and driver provided incidental observations from in front of vehicle.
4. Stopped at every ≥1 Burrowing Owl(s), and recorded the following information:

    A. Date
    B. Time
    C. Location, based on:
        i. GPS coordinates (Trimble GeoExplorer XM with GPS slider set halfway to balance productivity with precision and postprocessed differential correction)
        ii. Compass heading to owl/nest from observer (Suunto Handheld Directional Compass)
        iii. Distance to owl/nest from observer (Opti-Logic Laser Rangefinder with ±1 m accuracy)
    E. Type of location (nest burrow, no nest, flying, perched)
    F. Number of owls (1, 2, 3, …n)

5. Avoided errors in detection by not looking past the vehicle after stopping at an owl (except to track an owl that moved in order to avoid double counting) and not backtracking route.

Data Processing and Analyses

Processing and analyses of Burrowing Owl closed-population capture-recapture data entailed 3 general steps:

1. Development of capture-recapture encounter histories

   A. We used the point coordinate technique with a 55m radius buffer (which corresponds to the mean maximum distance moved (see Chapter 5))
   B. Created 5 individual encounter histories from the 64 routes:
      i. Encounter history dataset 1: First 2 occasions
      ii. Encounter history dataset 2: First 3 occasions
      iii. Encounter history dataset 3: First 4 occasions
      iv. Encounter history dataset 4: First 5 occasions
      v. Encounter history dataset 5: First 6 occasions

2. Closed population modeling

   A. Fit maximum-likelihood, closed-population models (Cooch 1999) to each capture-recapture encounter history dataset.
   B. Used the sin link function to link model coefficients to matrices because it allows for better estimation of the number of estimable parameters and of the shape of the log-likelihood function at its maximum, while constraining its parameter to be within 0-1 (White and Burnham 1999).
   C. Used deviance plots to heuristically assess model fit.

3. Minimum number of repeat sampling occasions needed to achieve accurate estimates of population size

   A. Computed coefficients of variation (CV) for each population estimate and plotted them against the number of survey occasions (Figure 6.2).
   B. Determined the minimum number of repeat survey occasions necessary for obtaining reliably precise estimates by identifying the number of survey occasions needed to achieve a $CV(\hat{N}) \leq 0.1$. We chose this cutoff because "reliable scientific studies … should try for a $CV(\hat{N}) \leq 0.1$" (White et al. 1982:50).
   C. Performed retrospective power analyses (Kuehl 1994, Steidl and Thomas 2001) with a specified range of effect sizes (changes in annual population size) to assess the relative statistical power of detecting a change in population size between the 5 encounter history datasets (2, 3, 4, 5, and 6 occasions). We used a one-tailed test (because adaptive management would be triggered only when the population would decline), an α=0.05,

and empirically based estimates of population size associated with the 5 encounter history datasets. We chose a range in population changes to yield power curves that would illustrate differences among sampling design scenarios and various changes in annual population sizes since an acceptable level of population change has yet to be determined for the demographic study (section 4.5.3 of the HCP Plan, dated June 2002).

RESULTS

Capture-recapture Results

We successfully computed CV($\hat{N}$)s and $\hat{N}$s for 300 of the 320 possible encounter histories (1 encounter history file for 2, 3, 4, 5, and 6 repeat sampling occasions x 64 routes). The 20 that were not estimated were generally those corresponding to low numbers of occasions (and hence low effective sample sizes), preventing the convergence of model likelihoods. The average detection probability was 0.63.

Minimum number of repeat sampling occasions needed to achieve accurate estimates of population size

1. Minimum number of repeat survey occasions to achieve a CV($\hat{N}$) $\leq$1 was 3.
2. Statistical power of detecting a change in the Burrowing Owl population increases with an increase in survey occasions; there was a marked increase in power from >2 occasions (Figure 6.3A).
3. Statistical power began to asymptote at 3 occasions (Figure 6.3B).

CONCLUSIONS AND RECOMMENDATIONS

We found clear evidence that a minimum of 3 survey occasions are necessary when using the point-coordinate capture-recapture technique in order to achieve an acceptable level of accuracy in estimating the abundance of male Burrowing Owl territories in the HCP Study Area. Three survey occasions nearly doubled the precision of $\hat{N}$ compared to using only 2 occasions. This high level of precision stemmed from our using 3 capture-recapture occasions on a species with high detection probabilities. For example, given the average detection probability/occasion we found here (0.63), the probability of that we <u>did</u> <u>not</u> detect a territory $\geq$1 times during the 3 occasions was 5.0% [i.e., $(1-0.63)^3$]; thus, the probability that we <u>did</u> detect a territory $\geq$1 times over the 3 occasions was 95.0% [i.e., $1-(1-0.63)^3$].

Our prospective power curve analyses showed that 3 occasions provided a marked increase in statistical power to detect a change in the annual Burrowing Owl population size compared to using 2 occasions. For example, the power curve associated with 2 occasions consistently provided the least power to detect a change at any level, and the addition of 1 more survey occasion increased power by as much as 11%. Coinciding with this increase, $\geq$4 occasions provided little improvement over 3, indicating that an increase in the number of surveys beyond 3 did not appreciably improve power, and

doing so would only be at an unnecessary expense (effort). Additionally, we advise against the use of only 2 occasions because that level of effort does not allow for the complex testing of assumptions and subsequent selection of a model from which to obtain unbiased estimates. Furthermore, the power curves began to asymptote at 3 occasions, substantiating the minimum number required to obtain the highest power to detect a change in abundance.

Prospective power analyses like these can aid in the development of future Burrowing Owl capture-recapture sampling designs because they provide a probability that a specified change in annual population change could be detected (Peterman 1990). Based on our results, we conclude that all vehicle-based point-coordinate capture-recapture surveys of Burrowing Owls (following our protocols) in the HCP should conduct 3 consecutive occasions. Fewer than 3 may provide poor accuracy and more than 3 may be an unnecessary expense.

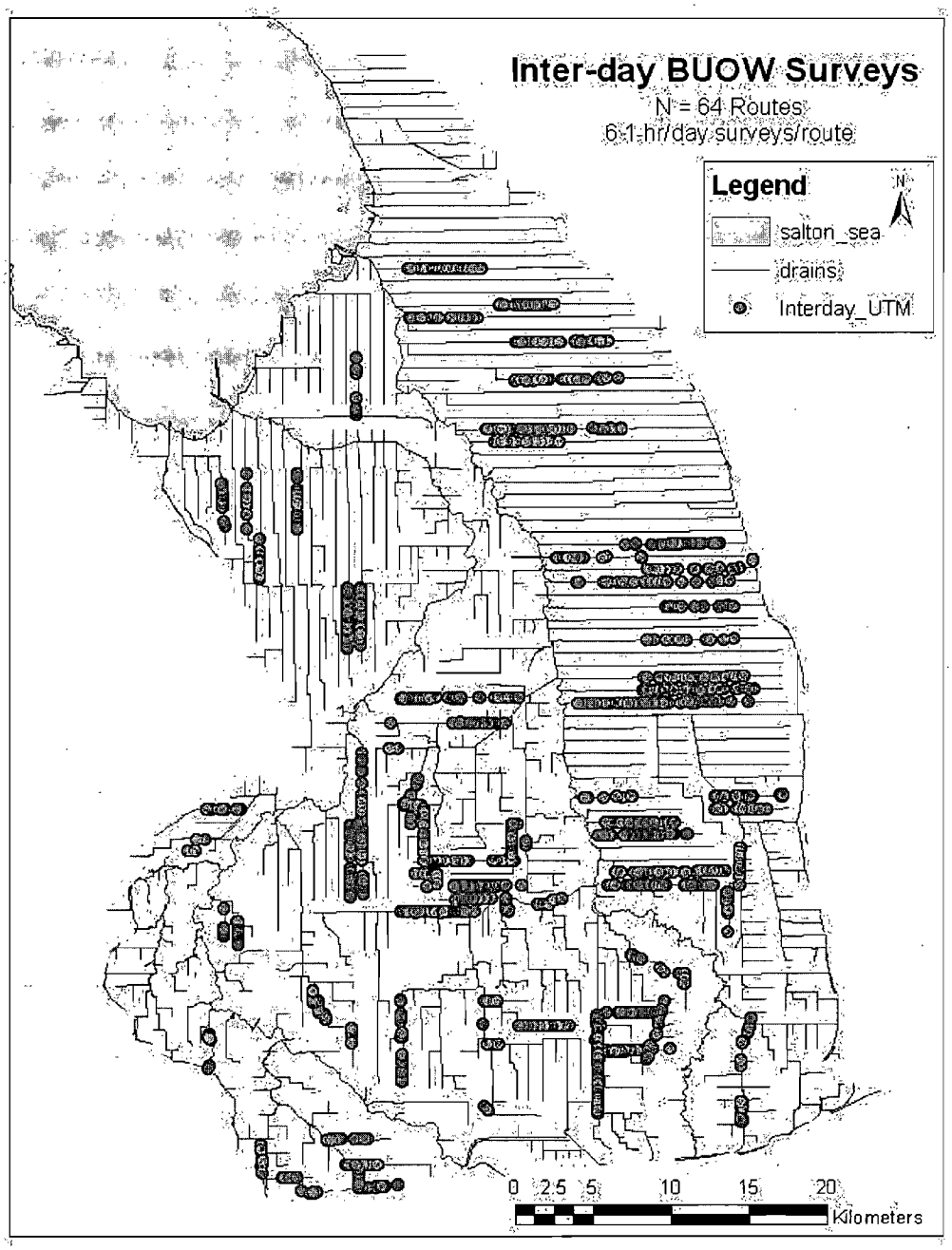


Figure 6.1. Routes where 6 consecutive days of diurnal, capture-recapture surveys were conducted for Burrowing Owls in the HCP Study Area, Imperial County, California. Points represent individual owl locations, April 16-May 20, 2006.

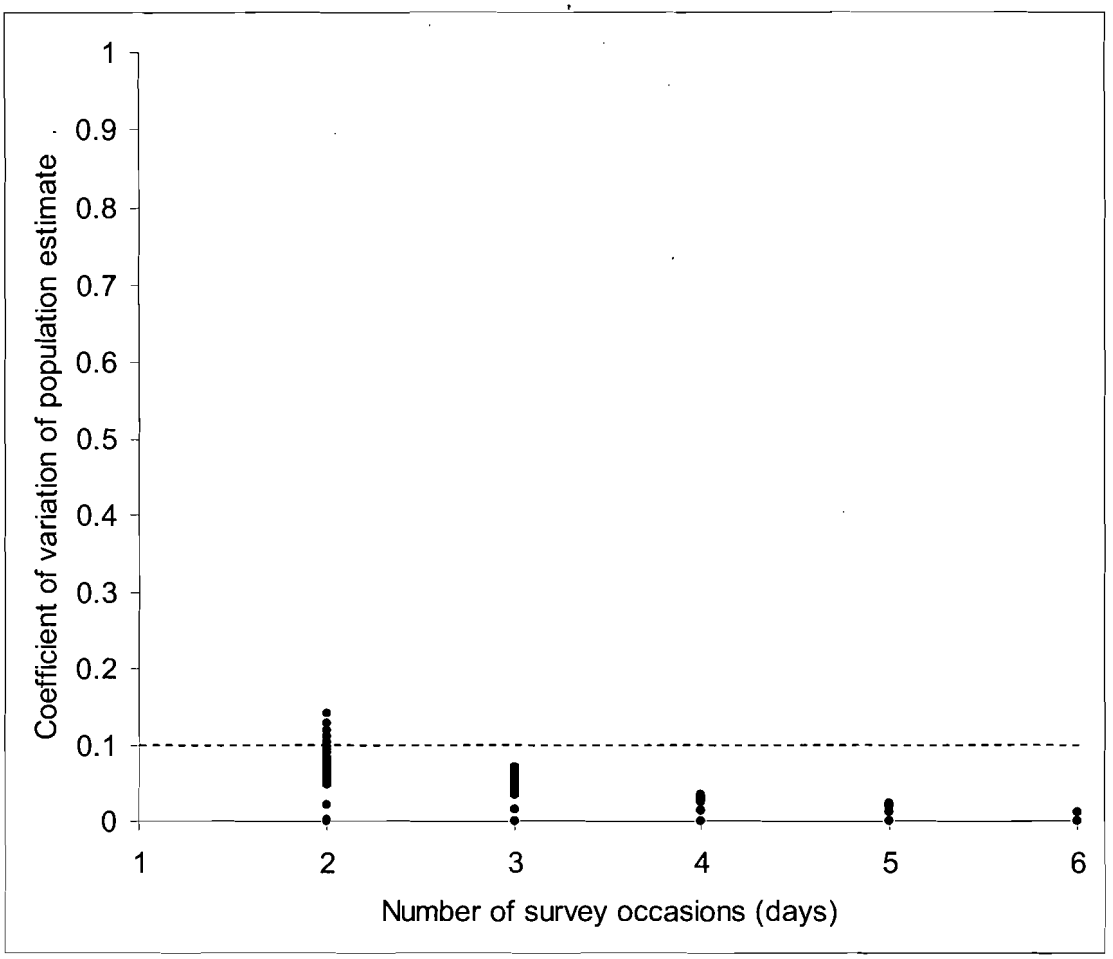


Figure 6.2. Coefficients of variation of population size as a function of the number of repeat survey occasions for male Burrowing Owl territories in the HCP Study Area, Imperial County, California, April 16-May 20, 2006. "Reliable scientific studies … should try for a $CV(\hat{N}) \leq 0.1$" (White et al. 1982:50).

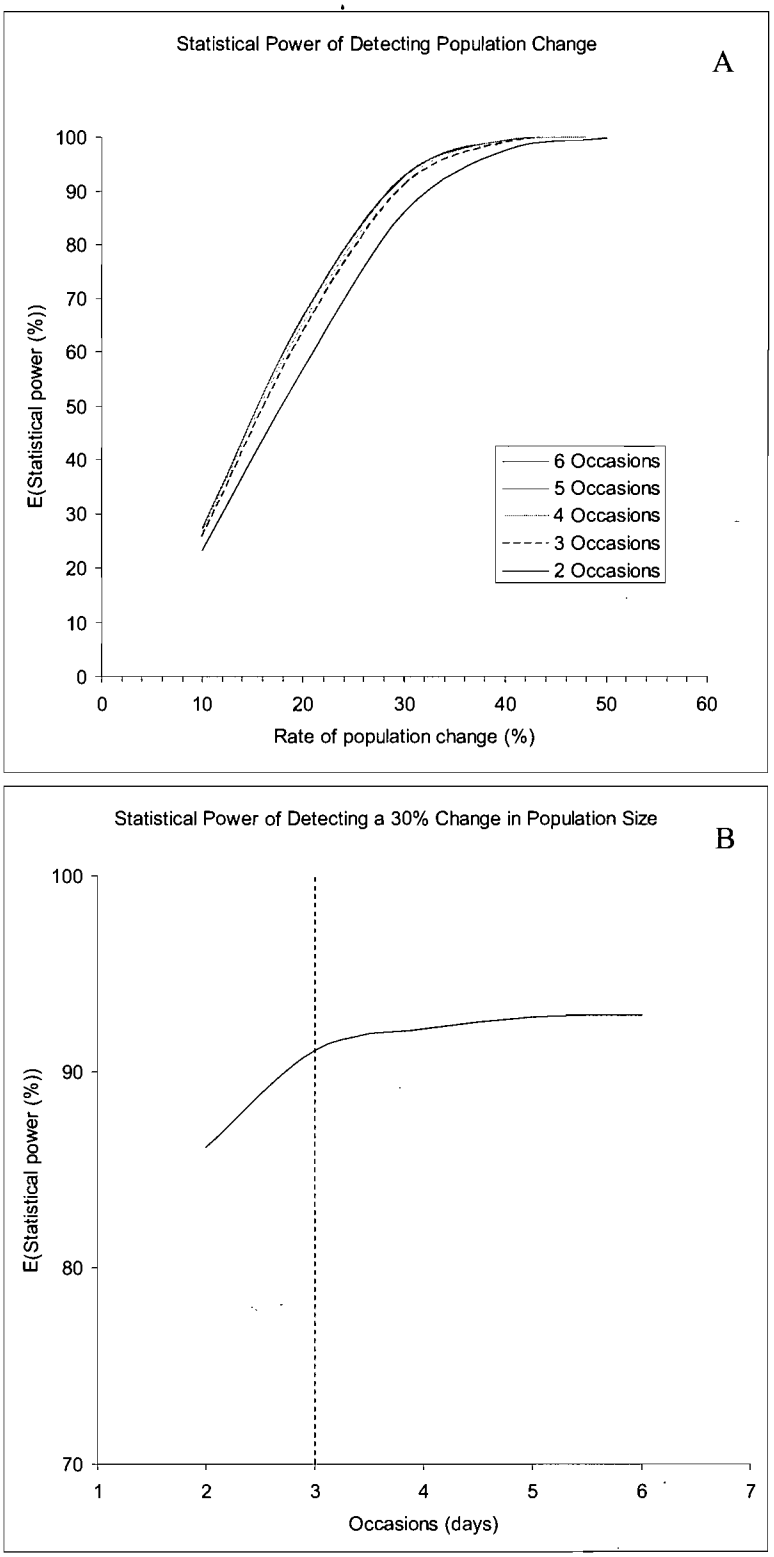


Figure 6.3. Retrospective power curves for various rates of Burrowing Owl population change (indexed by changes in population size) in the HCP Study Area, Imperial County, California, April 16-May 20, 2006. Power curves are in vertical order listed in legend.

Chapter 7

CLOSED-POPULATION CAPTURE-RECAPTURE SURVEYS IN 2007

JEFFREY A. MANNING

ABSTRACT. In this chapter, I present the results from conducting a complete census of male Burrowing Owl territories in the HCP Study Area during the prehatch stage of the breeding cycle in 2007 using the point-coordinate capture-recapture technique.

INTRODUCTION

Closed-population, capture-recapture methodology is a powerful approach for estimating the abundance of male Burrowing Owl territories in the Imperial Valley. This technique is based on marking and recapturing animals during repeated survey occasions. Repeated surveys are required to increase probabilities of detecting male owl territories and accuracy of population estimates (Otis et al. 1978). Generally, greater numbers of survey occasions increase the accuracy of population abundance (Otis et al. 1978, White et al. 1982). There is an optimal number, beyond which additional surveys would not improve accuracy appreciably and thus would constitute wasted effort. Based on preliminary analyses from a pilot study in 2006, we initially suggested that 4 occasions were appropriate; we therefore completed 4 survey occasions in 2007. However, as we reported in Chapter 6, a recent reanalysis of that data led us to recommend that the application of the point-coordinate capture-recapture survey technique to estimate the size of the owl population in the HCP Study Area requires only 3 survey occasions to achieve an optimal level of effort when following our survey protocols.

Achieving accurate population estimates from closed-population sampling methods depends on meeting the critical assumption of population closure (no emigration, immigration, births, or deaths) (White et al. 1982). We met this assumption demographically by conducting point-coordinate surveys in a brief period (≤30 days from April 2-May 3), which coincided with the prehatch stage of the breeding cycle, when females incubate and males remain sentinel outside the nest entrance (Martin 1973, Plumpton and Lutz 1993). This period began after migrant owls were thought to have departed from the Imperial Valley, ended prior to resident owls fledging young, and coincided with minimal movements of resident males away from burrows. The majority of resident females should have already been pair-bonded with males by the start of this period, and have been spending the majority of their time in the burrow. Thus, we minimized the risk of biasing estimates of male owl territories in the HCP Study Area by avoiding migrant and fledgling owls and surveying when males were expected to exhibit minimal movements away from nest burrows while females were unavailable for accidental double counting.

METHODS

We conducted diurnal, capture-recapture surveys for Burrowing Owls from April 2 – May 3, 2007 using the following detailed methods:

1. Conducted 4 point-coordinate survey occasions (1 occasion/day) along every IID right-of-way that paralleled an aboveground water conveyance structure (canal and/or drain) in the HCP Study Area. During each survey occasion, the vehicle traveled one side of an isolated drain or canal. Where ≥2 water conveyance structures paralleled multiple access roads within a single right-of-way and the field of view could be compromised by distance between the water conveyance structures (roughly ≥60 m) or topography, a survey was conducted on >1 of the roads to ensure complete survey coverage of the right-of-way while care was taken to not survey the same water conveyance structure twice (i.e., each water conveyance structure was surveyed from only one side).
2. Conducted diurnal, visual surveys by traveling the same direction during all 4 surveys.
3. Conducted the 4 surveys at approximately the same time of day (½-hr after sunrise to 1130 and 1600 to ½-hr before sundown) to avoid issues with reduced availability of owls during midday:

April 2-11:	0700-1130 and 1600-1830
April 12-23:	0650-1130 and 1600-1845
April 24-May 3:	0640-1130 and 1600-1850

4. Randomly partitioned the HCP Study Area into 6 routes (where a consecutive number of survey occasions completed along a route was considered to be a survey session; Figure 7.2), and completed each session with 1 vehicle (each having a driver and observer) traveling 7 mph in 4 days (e.g., 4 survey occasions/route). Vehicles were positioned so the observer was closest to drain/canal, observer surveyed passenger side of vehicle, and driver provided incidental observations towards the front of vehicle.
5. Stopped at every ≥1 Burrowing Owl(s), and recorded the following information (in ≤2 minutes) for the 1st owl detected at that stop and separately for any owl(s) >20 m from the first owl detected or in addition the first 2 owls seen:

   A. Date
   B. Time
   C. Location of burrow entrance <20m from the owl(s) that contained the highest number of signs of activity (e.g., an owl that retreats or flushes from burrow, regurgitated pellets, feathers, nest lining, whitewash, or footprints with an absence of cobwebs; Conway et al. 2008) or the closest burrow if multiple burrows revealed an equal amount of signs of activity. Location of owl, if no burrow is evident within 20 m.
      i. GPS coordinates (Trimble GeoExplorer XM with GPS slider set halfway to balance productivity with precision and postprocessed differential correction)

ii. Compass heading to owl/nest from observer (Suunto Handheld Directional Compass)
iii. Distance to owl/nest from observer (Opti-Logic Laser Rangefinder with ±1 m accuracy).

D. Detection method
E. Observed behavior (Flush/flying)
F. Fate
G. Type of location (nest burrow, no nest, flying)
H. Number of owls (1 or 2)
I. Type of perch:

i.	At burrow entrance	-- within the burrow entrance
ii.	On bare ground	-- on bare ground (with no veg or debris)
		-- on cement liner (with no veg or debris)
iii.	Flying only	-- never seen on the ground (wings flapping)
iv.	On pppwdfh	-- on fence post or stake
		-- on horizontal pipe
		-- on utility pole
		-- on utility or fence wire
		-- on debris pile (cement, dirt, gravel, other)
		-- on farm equipment
		-- on head gate
v.	In or on vegetation	-- in live or dead vegetation
		-- on live or dead vegetation
vi.	In agricultural field	-- in vegetated agricultural field
vii.	On hay bale(s)	-- on hay bale(s)
viii.	Other	-- any other structure or substrate, described

J. Texture within an approximated 8-degree radius circle centered on the detected owl from observer's view. This was based on a 6-m radius circle surrounding an owl at 21 m from the observer because many vantage points for detecting owls were approximately 21 m from where owls often perched (across the water conveyance structure).
K. Vegetation cover in the same circle used for measuring texture:
   i. 0%
   ii. 1-25%
   iii. 26-50%
   iv. 51-75%
   v. 76-100%
   vi. No vegetation because owl was silhouetted above horizon
   vii. No vegetation because owl was detected in flight
L. Leg band status:
   i. Banded
   ii. Unbanded
   iii. Unknown
M. Number of squirrels detected since previous owl location

6. Avoided errors in detection by not looking past the vehicle after stopping at an owl (except to track an owl that moved in order to avoid double counting) and not backtracking route in order to obtain detections primarily from the moving vehicle. If an owl was detected while not in the moving vehicle, the above information was recorded and a note that it was not detected from the moving vehicle.
7. Standardized observations by having the vehicle lights off, windows rolled up, come to a stop after passing detected owl to avoid flushing it forward into areas yet to be surveyed, and engine turned off upon stopping; also required all field biologists to participate in extensive training and field exercises; did not use cell phones, radio, and cameras while surveying.

This survey method essentially 'marked' or 'captured' each territory on the first date observed using global positioning system (GPS) coordinates. 'Recaptures' were successive recordings of GPS coordinates during subsequent sampling occasions, identified using the method described in Chapter 5.

RESULTS

We conducted 4 capture-recapture survey occasions along 3,960 Km of IID right-of-way that paralleled an above-ground irrigation canal and/or drain. We observed 3,461 male Burrowing Owl territories on the first capture-recapture occasion; on the second, we observed 3,685, the third 3,737, and the fourth had 3,748 (Figure 7.1). Owl locations by survey session are portrayed in Figure 7.2.

Obstacles that led to delays in our traveling along the IID right-of-ways included locked gates, farm equipment, piled hay bales, erosion, mud, sand, and restricted access to private property.

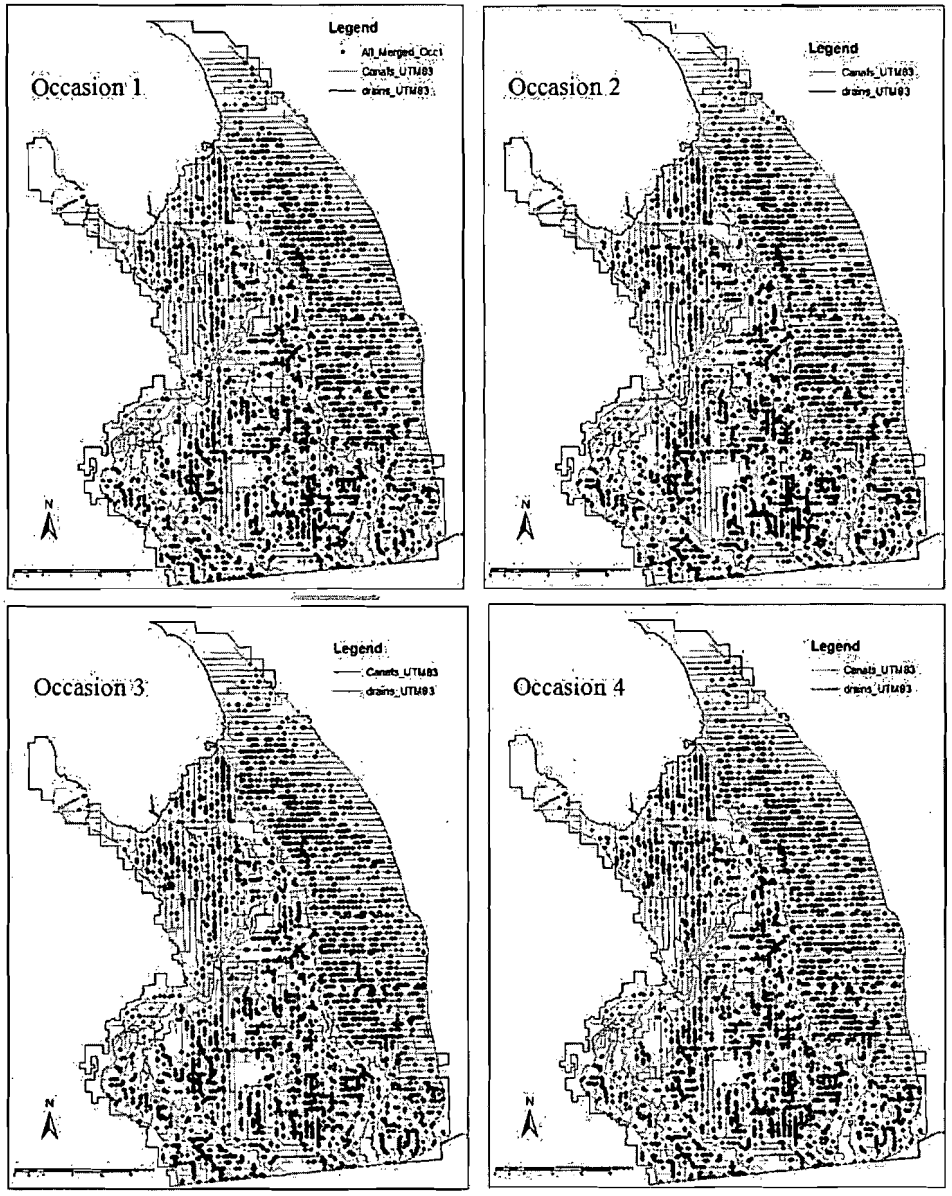


Figure 7.1. Point coordinate locations of male Burrowing Owls during capture-recapture survey occasions 1, 2, 3, and 4 from April 2-May 3, 2007.

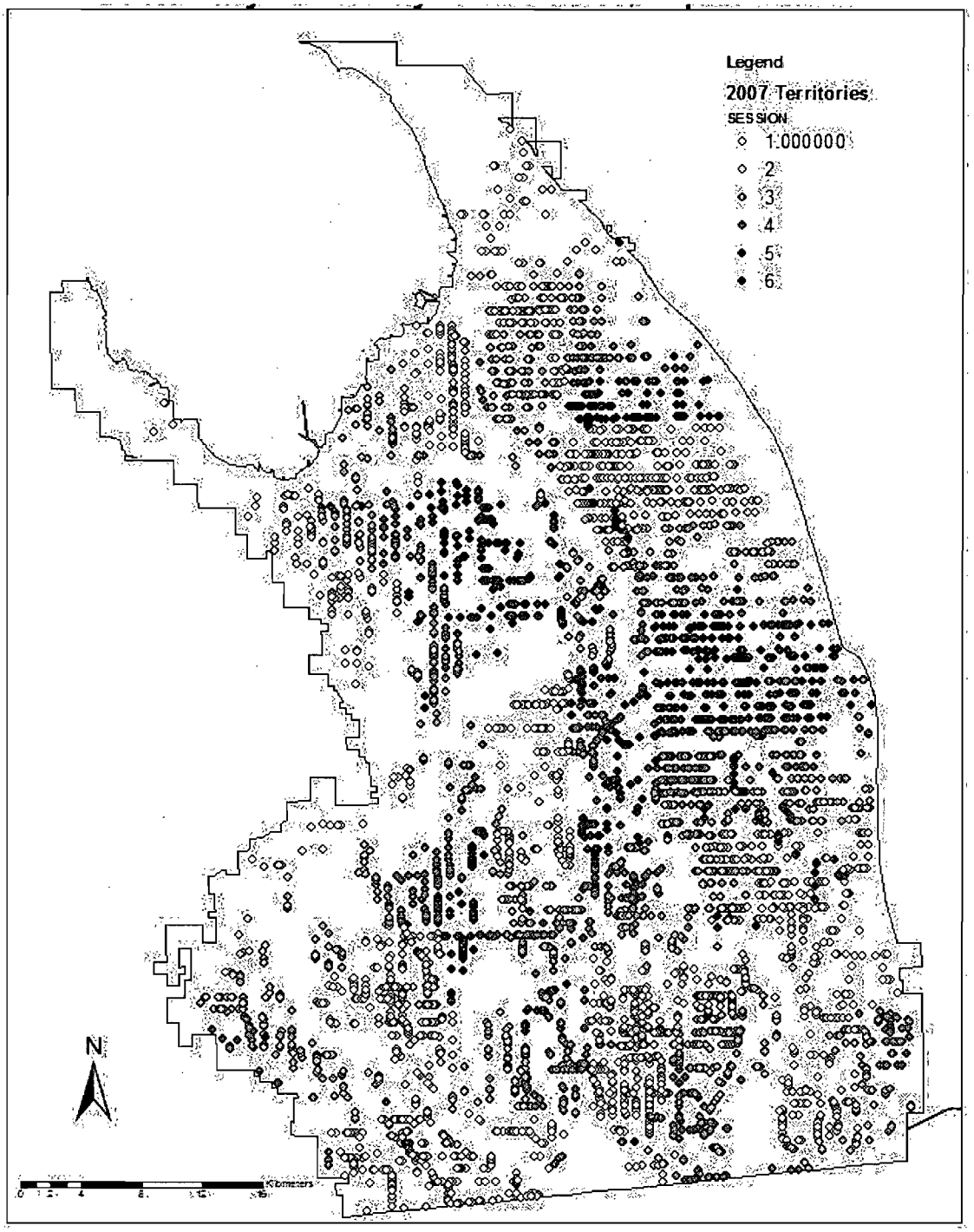


Figure 7.2. Locations of male Burrowing Owl territories coded according to 6 separate 4-occasion survey sessions during the prehatch stage of the breeding cycle across the HCP Study Area, Imperial County, California, 2007.

CONCLUSIONS AND RECOMMENDATIONS

These surveys of 3,960 Km of IID right-of-way that paralleled above-ground water conveyance structures during 6 4-day survey sessions over a 30-day period demonstrates that a complete census of the HCP Study Area during the prehatch stage of the breeding cycle is possible. The successful completion of these surveys was largely due to the absence of significant delays or postponements through intensive preplanning and training, and the cooperation and support of the IID staff. The IID staff informed private landowners in advance and during our surveys of the survey effort, provided gate keys upon our encountering locked gates, and shared additional support. Such collaboration would be essential for the success of any future HCP-wide census.

We conducted these 4 survey occasions prior to the new information we presented in chapter 6, which suggested that only 3 survey occasions are necessary to compute reliable estimates of population size in the HCP Study Area. The first 3 survey occasions of Burrowing Owl point-coordinates presented here provide the basis for constructing point-coordinate capture-recapture encounter histories, as described in Chapter 5, that will be used in chapter 8 to compute maximum likelihood estimates of male Burrowing Owl territory abundance in the HCP Study Area.

Chapter 8

MAXIMUM LIKELIHOOD ESTIMATE OF MALE BURROWING OWL TERRITORY ABUNDANCE IN THE HCP STUDY AREA IN 2007

JEFFREY A. MANNING

ABSTRACT. Maximum likelihood estimates of population size are widely considered to be the most reliable estimates attainable by wildlife scientists. Here, I present a maximum likelihood estimate of male Burrowing Owl territory abundance in the HCP Study Area using the data presented in Chapter 7. The data were pooled into a single capture-recapture encounter history and categorized according to six separate periods when the 3 survey occasions occurred. In the absence of sampling error or sampling units, this analysis estimated the population to be 4,998 (95% CI=4,946-5,081).

INTRODUCTION

The HCP specified the need to obtain annual estimates of the population of male Burrowing Owl territories in the HCP Study Area. One approach to achieve this would be to sample the HCP Study Area and extrapolate those results to the remainder of the area that was not sampled. Alternatively, a complete census could be used to estimate a single estimate. The latter approach is not cost effective on an annual basis. But, because our approach to develop a validated survey method relied on 2 consecutive years of complete censuses, we had the unique opportunity to utilize those data to compute annual estimates for those years. This chapter presents the estimated population size of male Burrowing Owl territories during the prehatch stage of the breeding cycle along the IID's rights-of-way in the HCP Study Area in 2007.

METHODS

I combined the encounter histories from all male Burrowing Owl territories across the entire HCP into a single encounter history dataset, and stratified it by 6 survey sessions, as described in Chapter 7. I used the closed-capture capture-recapture models with the sin link function available in Program MARK to fit 6 maximum likelihood models to these data (Table 8.1, Otis et al. 1978, White et al. 1982, Cooch 1999, White and Burnham 1999). All models estimated abundance for the portion of the HCP Study Area that was surveyed in each session, and assumed that detection and recapture probabilities were equal and either constant [$\hat{p} = \hat{c}$ (.)], vary across occasions [$\hat{p} = \hat{c}$ (t)], vary among sessions [$\hat{p} = \hat{c}$ (session)], or vary by the interactive effects of session and occasions ($\hat{p} = \hat{c}$ (session x t)). I used Akaike's Information Criterion adjusted for small sample sizes (AIC_c) to determine the most parsimonious model and considered this to be my best model (Akaike 1973, Burnham and Anderson 2002). I obtained estimates of abundance for each session ($\hat{N}_s$) from this model, and considered the sum of the abundance

estimates for the sessions ($\sum_{i=1}^{6} \hat{N}_s$) as the approximate true population size of male Burrowing Owl territories in the HCP Study Area in April 2007. I assessed the lack-of-fit of this model to the data by examining a plot of its deviance residuals. A symmetric and narrow pattern of deviance residuals close to zero would suggest a good fit to the data, whereas a wide pattern around zero would suggest poor fit due to extra-binomial variation.

Although I had initially proposed to include individual covariates (e.g., percent vegetation and texture) into the models, our approach of using buffered point coordinates restricted their use at this stage of analysis, as described under the conclusions and recommendations in Chapter 5.

RESULTS

The most parsimonious model showed that detection probabilities varied through time differently within each session (Table 8.1). This model fit the data well (deviance residuals followed a narrow and symmetric pattern surrounding zero), and estimated a total of 4,998 (95% CI=4,946-5,081) male Burrowing Owl territories in the HCP (Table 8.2).

Table 8.1. Closed-population capture-recapture models fit to male Burrowing Owl Territory encounter histories and their corresponding ΔAIC_c-values, Imperial Valley, California, April 2007.

Model Syntax	ΔAIC_c	AIC_c weight	No. of Parameters	Deviance
$\hat{p} = \hat{c}$ (session x time[1])	0	1.00	24	298.628
$\hat{p} = \hat{c}$ (session)	234.53	0.00	12	557.218
$\hat{p} = \hat{c}$ (time)	276.98	0.00	9	605.68
$\hat{p} = \hat{c}$ (.)	294.78	0.00	7	627.487

[1] Time refers to days (n=3), as a survey occasion occurred on each of 3 days.

Table 8.2. Estimates of detection and abundance of male Burrowing Owl territories during the prehatch stage of the breeding cycle in the HCP Study Area, Imperial County, California, 2007. Estimates are from the best closed-population model in Table 8.1.

	Detection and recapture probabilities (p=c) (SE)			
Session[1]	Occ. 1	Occ. 2	Occ. 3	$\hat{N}_s$ (95% CI)
1	0.71 (0.02)	0.67 (0.02)	0.79 (0.01)	897.4 (890.3 - 909.2)
2	0.68 (0.01)	0.69 (0.01)	0.77 (0.01)	1161.4 (1152.5 - 1175.1)
3	0.58 (0.02)	0.62 (0.02)	0.72 (0.01)	1102.1 (1088.2 - 1121.5)
4	0.64 (0.02)	0.78 (0.01)	0.52 (0.02)	985.7 (974.1 - 1002.6)
5	0.70 (0.02)	0.68 (0.02)	0.68 (0.02)	758.4 (749.9 - 771.8)
6	0.60 (0.05)	0.71 (0.05)	0.70 (0.05)	92.8 (90.7 - 100.4)
Entire HCP Study Area				4998.0 (4948 - 5081)

[1] Refers to 3 consecutive survey occasions in 6 different geographic portions of the HCP Study Area.

CONCLUSIONS AND RECOMMENDATIONS

Based on the closed-population point-coordinate capture-recapture estimation procedure used there, the estimate of 4,998 (95% CI=4,946-5,081) best approximates the true population size of male Burrowing Owl territories in the HCP Study Area in April 2007.

Chapter 9

EVALUATION OF SPATIAL AUTOCORRELATION IN MALE BURROWING OWL TERRITORY ABUNDANCE AND THE DETERMINATION OF A STANDARDIZED SAMPLING GRID

JEFFREY A. MANNING AND STACIE ROBINSON

ABSTRACT. A standardized sampling grid across the HCP Study Area would standardize a population of sampling units that could be sampled annually for estimating and comparing Burrowing Owl population sizes. We present the results on an analysis of spatial autocorrelation in owl abundance to identify an appropriate resolution of a standardized sampling grid intended for use in sampling the HCP Study Area for Burrowing Owls in subsequent years. In accordance with Amendment 1, and based on the needs of the analytical survey and sampling methods, we determined that a 3x3 km grid cell resolution was appropriate for establishing a standardized grid.

INTRODUCTION

The original HCP document required that the relative abundance and distribution of owls be determined (section 4.5.2.2). In order to evaluate relationships between correlates and abundance, a standardized unit to measure abundance is needed. Such sampling units should be independent from one another. Since levels of Burrowing Owl abundance are believed to vary across the HCP Study Area, we suspect that abundance may be spatially auto-correlated, in which case independence has a spatial component to it. Fortunately, spatial statistics can be used to evaluate at what resolution spatial independence of male Burrowing Owl territory abundance may occur in the HCP Study Area. We initially proposed using the linear distance of the IID's rights-of-way for this analysis, but later proposed and received approval for an amendment to this (see executive summary), which entailed the evaluation of grids of various grid cell sizes to evaluate spatial autocorrelation. The intent of such an analysis would be to determine a standardized sampling grid.

A standardized sampling grid would standardize a population of sampling units that serve the purpose of making comparisons between annual population estimates over the 75-year permit of the HCP. Data currently available and suitable for an evaluation of grid cell sizes comes from the owl surveys presented in the previous chapter. These data are from a census of the HCP Study Area, the methods were thorough and standardized, and they provide an opportunity to assess possible relationships in spatial patterns of owl abundance. Because these data are empirical, their use comes with the assumption that they are from a population of owls that exhibit an approximate distribution and pattern of local abundances typical to that expected to be present over the life of the HCP.

Spatial patterns provide information about the processes that affect ecological communities (Fortin and Dale 2005), as well as information to best model systems where

data are not spatially random (Haining 2003). Assessing spatial autocorrelation is a basic, but critical, step in assessing data structure and describing spatial patterns. Spatial autocorrelation describes the degree to which similarity in data values is dependent on spatial proximity (Haining 2003). The extent of spatial dependence can be used to describe ecological structure and define the extent of biological communities (Fortin and Dale 2005, Heywood 1991). The definition of ecological neighborhoods based on the extent of spatial autocorrelation has even been used to define units for conservation and reserve design (Diniz-Filho and Telles 2002).

Sampling designs and distributions of selected sampling units can affect the spatial pattern observed in the data, and may influence a researcher's ability to infer the true spatial structure in an ecological system (Tobin 2004). This is especially true of complex ecological systems like the Imperial Valley, where numerous environmental factors may combine to affect the spatial distribution of Burrowing Owls (Legendre and Fortin 1989). The census of owls across the HCP Study Area that were conducted in the IID's rights-of-way (see previous chapter) does not represent a sample and therefore should not affect the spatial pattern we observe. We are confident that the data enables us to capture the true patterns in the distribution of male Burrowing Owl territories.

In looking at the abundance of male Burrowing Owl territories across the Imperial Valley, we needed to decide on an areal unit of analysis in which to compute abundance. The definition of analysis units and the scale of spatial analysis can substantially affect the extent and intensity of spatial pattern observed (Turner et al. 1989, Wiens 1989). The manner in which we divide the study area into sampling units to assess abundance could therefore influence the spatial patterns (i.e. the degree of spatial autocorrelation) we observe. We chose square sampling units because they have smaller perimeter lengths per unit area than rectangular units and therefore less potential for error in including individuals in a unit. Square units are generally easier to map out than rectangular ones. Square units can also be used to easily subdivide a study area into non-overlapping areas without excluding areas, which is not the case with circular units.

It has long been established that spatial analyses should be carried out at multiple scales to get the most accurate picture and to detect confounding influences of scale on spatial patterns (Mead 1974). In order to assess scale effects and decide upon an areal unit of analysis for computing owl abundance, we performed spatial analyses at multiple resolutions using variable grid cell sizes to partition the study area.

METHODS

Autocorrelation – Moran's *I* Correlogram

1. Used the maximum number of owls observed during the 4 occasions for grid cell counts.
2. Grid cell sizes were 1x1 km, 2x2 km, 4x4 km, 8x8 km, 10x10 km, 11x11 km and 12x12 km.
3. Computed density of owls in grid cells as count/km of IID linear right of way.

4. Constructed Moran's *I* correlogram.
    A. Moran's *I* provides an autocorrelation measure that is similar to a Pearson's correlation coefficient, and ranges from -1 to 1 (Moran 1950).
    B. A negative Moran's *I* would suggest that similar densities were over-dispersed, or spread farther than expected at random.
    C. A positive Moran's *I* would indicate that similar densities were clustered or closer together than expected at random.
    D. The correlogram is a graph of the Moran's *I* coefficient calculated at multiple distance thresholds (i.e. Moran's *I* is first calculated according to all pairs of nearest neighbors, then all pairs of 2nd order neighbors, then 3rd, 4th etc.). In this way we graphed the decay of spatial dependence between neighbors as the distance separating them increased (Fortin and Dale 2005, Haining 2003, Rangel et al. 2006).
5. Used program SAM – Spatial Analysis for Macro-ecology (Rangel et al. 2006)
    A. Number of distance classes used coincided with 80 km [the approximated longest distance across the HCP divided by grid cell size (i.e., the number of neighbors expected to span the maximum distance across the HPC)].
    B. Used Queen's adjacency scheme (included neighbors on all sides and corners)

Autocorrelation - Variogram

1. Constructed semivariograms (refered to as variograms)
2. The variogram plots variance between sampled pairs against distance
3. The variogram can be seen as a compliment or inverse of the correlogram – where as the correlogram shows the breakdown in correlation at increasing distance, the variogram graphs the increase in variance between sampled pairs as the distance between them increases (Cressie 1991, Fortin and Dale 2005, Haining 2003, Ribeiro et al. 2003)
4. The variogram curves upward as long as the variance between samples increases with distance, at some point the curve levels off where distance no longer influences the variation between samples – this point is called the sill
5. Calculated variograms using geoR (Ribeiro et al. 2003), a package in the R statistical environment (Ihaka and Gentleman 1996)
6. Both classical and modulus models were used for completeness (Cressie 1991)

Determination of a Standardized Sampling Grid

We received a joint assessment of our results from the above analyses by Dr. Manly (WEST, Inc., Laramie, WY). His assessment required the further analyses at intermediate grid cell sizes (Figure 9.2). In light of the need to establish a grid that would be appropriate for stratified random sampling, this assessment was based on the following issues:

1. Large enough to support reasonably sized numbers of owls for capture-recapture modeling.

2. Large enough to support a range of abundances (including zero) for estimation purposes.
3. Small enough to support a large population of cells necessary for stratified random sampling.
4. Small enough to reduce washing out variation in covariates of abundance.

We developed a standardized sampling grid in ArcGIS 9.2 (ESRI, Redlands, CA) based on the assessment from Dr. Manly and laid it over the HCP Study Area. In doing this, some grid cells along the border of the HCP Study Area encompassed non-HCP Study Areas; to avoid inclusion of these areas, we refined the geographic extent of that grid by clipping it to the boundary of the HCP Study Area. However, clipping led to non-square cells along the boundary. In order to maintain grid cells of approximately equal size (which is advantageous for survey logistics and with the stratified random sampling framework described in Chapter 15), we combined some of these individual cell fragments that contained IID water conveyance structures to approximate the size of the standardized cell size. We removed cells that lacked any IID water conveyance structures, as these were not surveyed during this study.

RESULTS

We found that the abundance of male Burrowing Owls was spatially autocorrelated across the HCP at all grid cell resolutions we examined (Figure 9.1). Based on the subsequent assessment with Dr. Bryan Manly (Figure 9.2), it was determined that the 3x3 km grid cell provided a fairly large number of cells ($n = 274$), which contained reasonable numbers of owls for capture-recapture modeling and should be sufficient for stratified random sampling. This size reflected a balance of assessed issues; larger cell sizes reduced the number of cells available for stratification and smaller cells reduced sample sizes for capture-recapture modeling. The final, refined, standardized sampling grid produced 274 grid cells, with some clipped and combined cell fragments along its border approximating the 9 km^2 cell size (Figure 9.3).

CONCLUSIONS AND RECOMMENDATIONS

Based on the presence of spatial autocorrelation in the abundance of male Burrowing Owl territories across the HCP Study Area, we did not find a grid cell size that eliminated the autocorrelation among sampling units. Recognizing the need to establish a standardized grid from which to sample owls from so comparable estimates can be made in subsequent years, we chose to focus on the additional needs to adequately stratify the HCP Study Area. Based on Dr. Manly's assessment, we conclude that a 3x3 km grid cell would be appropriate for performing the current analyses and future surveys and analyses of male Burrowing Owl abundance.

This grid is intended for use in future surveys through the 75-year period of the HCP, from which a new random sample of grid cells should be obtained each year. This conclusion is based on our analyses of empirical owl data collected in 2007, and assumes that the data represent the typical distribution and abundance of owls across the HCP in

subsequent years. As recommended by Dr. Manly, because spatial autocorrelation is inevitable, it needs to be assessed and accounted for the final model used to estimate abundance of male Burrowing Owls in the HCP Study Area.

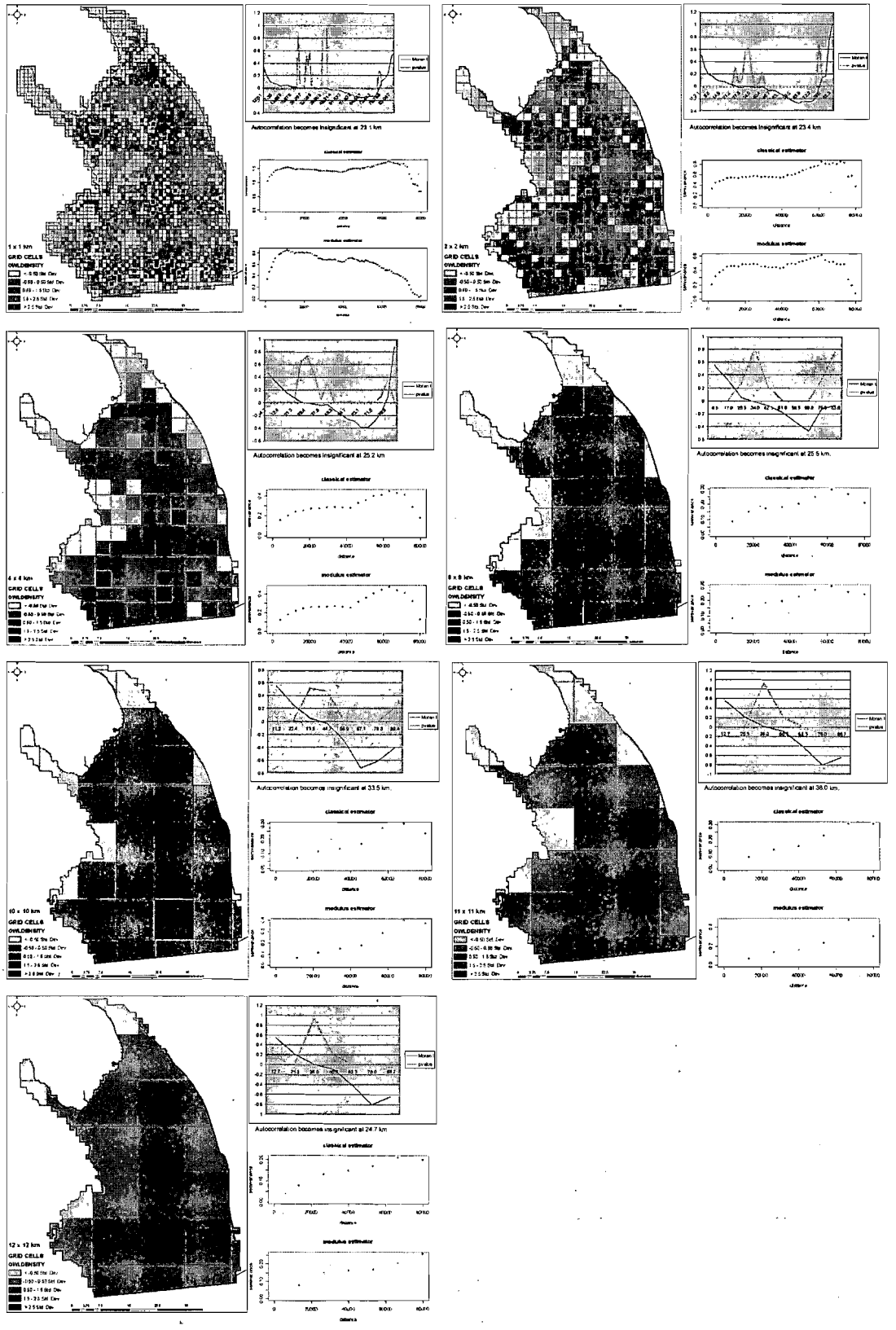


Figure 9.1. Spatial autocorrelation Moran's I, correlogram, and variogram results.

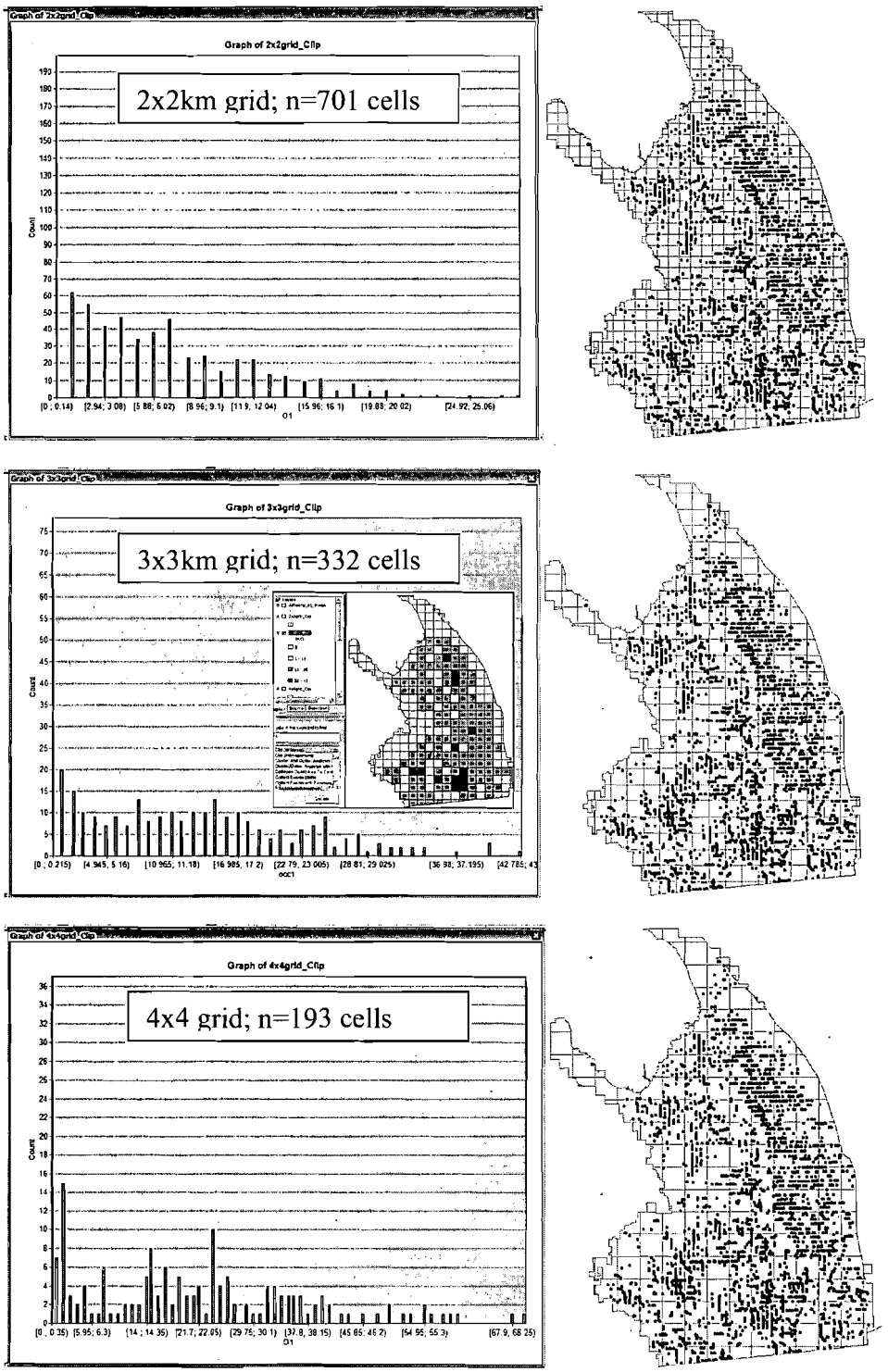


Figure 9.2. Histograms and figures of owl abundance at various grid cell sizes included as part of an assessment of results by Dr. Bryan Manly (WEST, Inc., Laramie, WY).

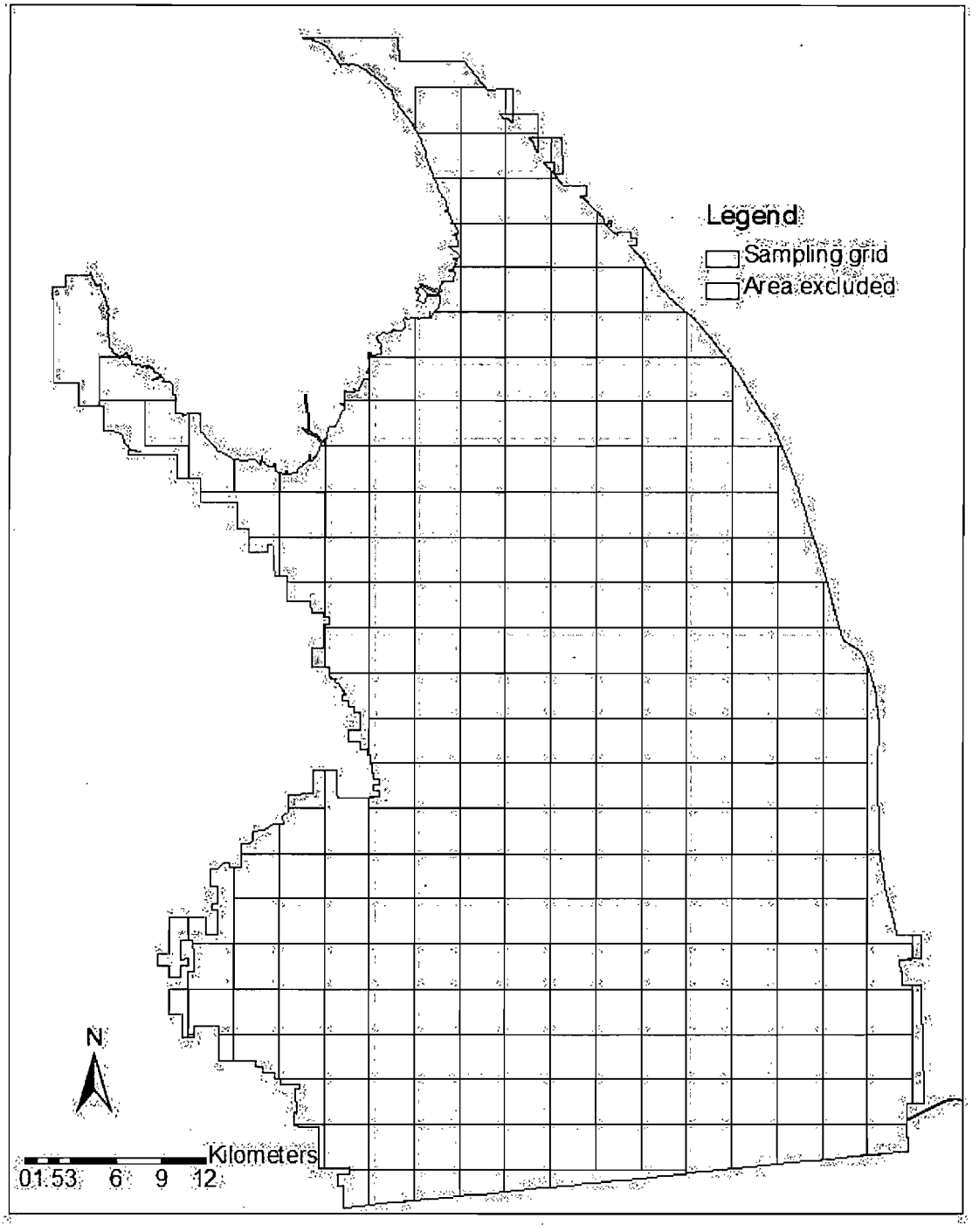


Figure 9.3. Standardized grid of 274 3x3 km sampling units for surveying Burrowing Owls in the HCP Study Area, Imperial County, California. Excluded areas are those where IID water conveyance structures were absent at the time of this survey, April 2007. Some cells along the boundary approximate 9 km^2 due to clipping and combining.

Chapter 10

MAXIMUM LIKELIHOOD ESTIMATES OF LOCAL MALE BURROWING OWL TERRITORY ABUNDANCE IN 2007

JEFFREY A. MANNING

ABSTRACT. Individual grid cells across the HCP Study Area can be used to adequately represent local Burrowing Owl territory abundances for comparisons across the area and annually. I calculated maximum likelihood estimates of local male Burrowing Owl territory abundance for each 3x3 km grid cell in 2007. To satisfy Amendment 6 and provide a total population estimate that could be compared as an approximation to the true population size to estimates calculated from sampling the data (as done in later chapters), I summed the abundances among the grid cells. Local abundances varied from 0-54 territories, and the approximated true population size was 4,879 (95% CI: 4,847 - 5,387).

INTRODUCTION

The HCP specified the need to obtain annual population estimates of male Burrowing Owl territories in the HCP Study Area. A complete census conducted annually could be used to obtain annual population sizes. However, such an extensive annual effort would be cost prohibitive and would still have to account for errors attributable to detection below 100%. A more practical and cost effective approach commonly applied by wildlife scientists would be to randomly sample portions of the HCP Study Area and extrapolate those results to the remainder of the area that was not sampled. This is because a random selection of sample units from an available population of units can yield statistically and biologically reliable population estimates. It is important to note that the population of Burrowing Owls is not the same as the population of grid cells referred to here for sampling. In order to have a population of sampling units to draw random samples from and compute local abundances annually, we developed the grid of 3x3 km cells in the previous chapter.

The goal to develop a validated long-term survey methodology (as proposed in Tasks 5 and 6 under Objective 2 of the final detailed study plan, dated January 31, 2007) relied on the acquisition of empirical estimates of population abundance (i.e., local abundance) in each grid cell. I intended to repeatedly draw random samples of cells from the 2007 census of grid cells to determine an optimal level and allocation of sampling that could be used in subsequent surveys to achieve a population estimate that would approximate that which could be obtained from a census of all grid cells (as presented in Chapter 15).

The power of such a sampling approach depends on the successful reduction in measurement error while surveying for owls in grid cells. This is because the analytical tools available for analyzing stratified random sampled data assume perfect counts in sampling units (no error in counts). Those tools, however, do account for the variation in abundance among grid cells, which is referred to as sampling variance. Thus, an important objective in surveying owls for the purpose of determining local abundances

must be to minimize measurement error during surveys. Fortunately, the field methods presented in Appendix II can be used with the point-coordinate capture-recapture analytical technique presented in Chapter 5 to achieve negligible levels of measurement error in estimates of local abundance. Here, I present maximum likelihood, point-coordinate, capture-recapture estimates of local male Burrowing Owl territory abundance in 3x3 km grid cells across the HCP Study Area and discuss their associated estimates of measurement error. Per amendment 6, I also used these data to calculate an approximate true number of Burrowing Owl territories in the HCP Study Area that is appropriate for comparing HCP Study Area-wide abundance estimates derived from random samples drawn from the population of grid cells.

METHODS

I considered a single survey pass along an IID right-of-way on a single day as a survey occasion, and consecutive occasions as a survey session (e.g., see Chapter 7). Thus, each of the 6 survey sessions described in Chapter 7 were comprised of a distinct set of survey occasions (i.e., 6 survey sessions, each in a distinct portion of the HCP Study Area, comprised of 4 single-day occasions = 24 days of surveys). Because the 6 sessions also corresponded with 6 different portions of the HCP Study Area that were surveyed at different days, I tested for time effects separately in grid cells according to each session.

Because the stratified random sampling approach to developing a long term survey protocol for owls is reliant on reducing measurement error when survey for owls inside grid cells, I used the point-coordinate capture-recapture technique (presented in Chapter 5) in analyzing owls survey data. I used the following methods to compute local, maximum likelihood, closed-population estimates of male Burrowing Owl territory abundance:

1. Applied the point-coordinate capture-recapture technique to the first 3 survey occasions, using the 55 m radius MMDM buffer recommended in Chapter 5. My use of only the first 3 occasions was based on the results presented in Chapter 6. This technique developed centroids associated with individual, point-coordinate-based, capture-recapture encounter histories.

2. To meet the HCP's requirement to estimate the abundance of breeding male territories and because I showed that owls in the HCP Study Area have a high probability of being detected during our surveys (95%; Chapter 6), I removed individual encounter histories from the dataset where a single owl was observed on only 1 of the 3 occasions and without a nest (Table 10.1). This is because owls had a high probability of being detected near their nests (see results, this chapter), and I assumed that such observations were of non-breeding owls that were not maintaining breeding territories at the time of our survey, or owls that were away from their territories at the time of observation. I considered the remaining centroids established above to be those of territorial males.

3. Overlaid the grid of 274 cells (see Figure 9.3 for grid details) onto the centroids of male Burrowing Owl territories and associated capture-recapture encounter histories determined above, and assigned each encounter history to its corresponding grid cell. I therefore used the 3x3 km grid cell as the areal unit to calculate local abundance estimates.

4. Determined in which of the 6 sessions the majority of a grid cell was surveyed, and grouped grid cells by the 6 sessions, and applied closed-population models with the sin link function available in Program MARK (Otis et al. 1978, White et al. 1982, Cooch 1999, White and Burnham 1999) to each grid cell and tested for time effects (among occasions) separately among the 6 survey sessions. Within each session, I fit models to each cell's set of encounter histories that assumed that detection and recapture probabilities were equal and constant [$\hat{N}$ (grid cell) $\hat{p} = \hat{c}$ (.)] or varied through time [$\hat{N}$ (grid cell) $\hat{p} = \hat{c}$ (time)], where time referred to occasions 1, 2, and 3. I used Akaike's Information Criterion (AIC_c; Akaike 1973, Burnham and Anderson 2002) to determine the most parsimonious model for a grid cell, and considered it to be the best model for that cell. I assessed the lack-of-fit of the model to the data by examining a plot of its deviance residuals. A symmetric and narrow pattern of deviance residuals close to zero would suggest a good fit to the data, whereas a wide pattern around zero would suggest poor fit due to extra-binomial variation.

5. Added the associated estimates of abundance and standard error from the best models into the corresponding grid cell in the GIS grid layer. Here, the standard error was a measure of precision that represented the error attributed to the point-coordinate capture-recapture surveys, which can be appropriately referred to as measurement error.

Although I initially proposed the inclusion of individual covariates (e.g., percent vegetation and texture) in models, the point-coordinate capture-recapture technique restricted their use at this stage of analysis, as described under the conclusions and recommendations in Chapter 5.

In order to have an estimate of the total population for comparisons with estimates obtained from sampling, I summed the local estimates from all 274 sample grid cells.

RESULTS

Raw counts during single survey occasions ranged from 3,451-3,726 (Table 10.1). The best capture-recapture models for most survey sessions represented the hypothesis that detection probabilities varied through time (day; Table 10.2), and most of these models fit the data fairly well (deviance residuals followed a fairly narrow and symmetric pattern surrounding zero). Estimates of male Burrowing Owl territory abundance ranged from 0 to 53.96/3x3 km grid cell (SE = 1.26), and those with a lower estimated abundance tended to be from smaller samples of owls and models having relatively greater spread in the deviance residuals. The mean abundance of the 274 cells was 17.8 owl territories (St

Dev = 13.2), and 18 cells were estimated to not contain owls during our surveys (Figures 10.1 and 10.2).

The majority of local abundance estimates had small standard errors, indicating small measurement errors. Nearly half of the grid cells, those cells where abundance was estimated to be ≤20 territories, contained very low standard errors, suggesting either negligible measurement error or poor performance of the capture-recapture models fit to those cells (Figure 10.1).

By summing the local abundances obtained from this method, we estimated the total population of male Burrowing Owl territories in the HCP Study Area in 2007 at 4,879 (95% CI: 4,847 - 5,387).

Table 10.1. Number of Burrowing Owl detections by survey occasion during the prehatch stage of the breeding cycle in the HCP Study Area, Imperial County, California, 2007. Owls detected once and without a nest were removed from the data.

	Survey Occasions		
Type of detection	1	2	3
Once without nest	165	221	232
All other detections	3,286	3,447	3,494
Mean/cell[1]	9.8	10.7	10.6
Standard deviation/cell[1]	12.6	13.4	13.6

[1] Calculated with total detections from all 274 3x3 km grid cells.

Table 10.2. Best closed-population capture-recapture models and detection estimates by session. These best models have ΔAIC_c-values = 0; their AIC_c-values that are not comparable to each other because AIC_c was used to select each of them from another model separately for each session, and those models are not included here.

		Survey Occasion		
Session	Best model	1	2	3
1	$\hat{p} = \hat{c}$ (time[1])	0.71 (0.02)	0.70 (0.02)	0.79 (0.01)
2	$\hat{p} = \hat{c}$ (time)	0.69 (0.01)	0.70 (0.01)	0.78 (0.01)
3	$\hat{p} = \hat{c}$ (time)	0.61 (0.02)	0.67 (0.02)	0.73 (0.01)
4	$\hat{p} = \hat{c}$ (time)	0.67 (0.02)	0.76 (0.01)	0.58 (0.02)
5	$\hat{p} = \hat{c}$ (.)	0.70 (0.01)	0.70 (0.01)	0.70 (0.01)
6	$\hat{p} = \hat{c}$ (.)	0.76 (0.06)	0.76 (0.06)	0.76 (0.06)

[1] Time refers to days, as a survey occasion occurred on each of 3 days.

CONCLUSIONS AND RECOMMENDATIONS

The use of 3 closed-population point-coordinate capture-recapture survey occasions resulted in a high probability (97.6%) of detecting a male Burrowing Owl territory ≥1

times over the 3 occasions, which is similar to that reported in Chapter 6. Specifically, given the average detection probability over occasions and sessions ($\hat{p} = 0.71$), the probability that a territory was detected ≥1 times over the 3 occasions was 97.6% [i.e., $1-(1-0.71)^3$].

This approach did not allow for modeling effects of individual covariates (e.g., amount of vegetation or type of drain or canal bank) on detection probabilities (see Chapter 5 for further details). However, given the high overall high detection probability from 3 survey occasions, such an analysis, if possible, may not have provided a marked improvement in bias or precision.

The low standard errors associated with estimates where territories numbered <20/grid cell (Figure 10.1) were likely due to the performance of the closed-population capture-recapture models that were fit to the data in Program MARK. Although this may lead to slightly biased low abundances when the number of owls is small within a grid cell, capture-recapture methods produce encounter histories for each individual owl, even if they are missed on all but one of the occasions, leading to a 97.6% chance that each territory will be accounted for. Unlike capture-recapture, which utilizes these repeated occasions to increase the number of individuals detected and thereby account for imperfect probabilities of availability when numbers are high enough, other survey methods which can minimize measurement error due to visibility bias (e.g., distance sampling, point counts, and sightability) do not correct for availability bias. This is problematic with species where availability may vary throughout the day like the Burrowing Owls in the HCP Study Area (i.e., see Figure 2.4). Variation in availability among days can also be a problem, as we found that the raw counts associated with the capture-recapture occasions conducted here were variable among days. Given the standardized and constant levels of effort applied only days apart during the owl surveys, it is unlikely that the 6% difference in counts among the 3 occasions was due primarily to visibility bias, but rather also imperfect availability of individuals among the days. Currently, capture-recapture is one of the more powerful methods to estimate abundance from species like the Burrowing Owl where visibility and availability bias affects measurement error, and hence population estimates. Until advances are made with methods that rely on a single survey occasion that will correct for imperfect availability as well as detectability while producing precise, unbiased estimates, capture-recapture methods are recommended for estimating local abundances in the HCP Study Area.

Closed-population models in Program MARK are widely accepted in wildlife science, and they allow for evaluating variable detection probabilities. The program also incorporates the ability to compare models using the information theoretic approach. One alternative to using Program MARK while maintaining the use of capture-recapture methods with such small sample sizes would be to use the model developed by Chao (1989). This model is unavailable in Program MARK. Currently, I am unaware of any statistical-based closed-population platforms that include the Chao estimator, other than Program CAPTURE, which does not have a reliable model selection procedure. Thus, applying the Chao (1989) model would preclude modeling variable detection probabilities or comparing multiple working hypotheses, which in itself could lead to

imprecise, biased estimates. It also does not perform as well as other closed-population models with larger samples.

In order to accomplish the proposed objective of evaluating the level of bias associated with various sampling methods and randomly drawn samples (to be completed in Chapters 15 and 17), an estimated abundance that best approximates the true total population size in the HCP Study Area is needed. Although we provided a maximum likelihood estimate of male territories in the HCP Study Area in Chapter 8, that estimate was calculated by pooling the complete census data into a single dataset and partitioning and analyzing it by survey session without considering the standardized sampling grid. Those data and analytical methods differ from those that will be used in future surveys, which will rely on surveys in grid cells that are to be randomly drawn from the standardized sampling grid. As suggested by Dr. W. R. Gould (New Mexico State University, Las Cruses) in his independent review, dated January 8, 2007, those differences preclude using the estimated population total from Chapter 8 as a basis for comparing estimates obtained from sampling the HCP Study Area. Because the sampling grid is intended for future surveys and will be the basis for drawing random samples in simulations intended to test different sampling methods and levels of random sampling in Chapters 15 and 17, the sum of the local 2007 abundances in grid cells [4,879 male Burrowing Owl territories (95% CI: 4,847 - 5,387)] is an appropriate estimate of the true population size for comparing with the simulated sample estimates.

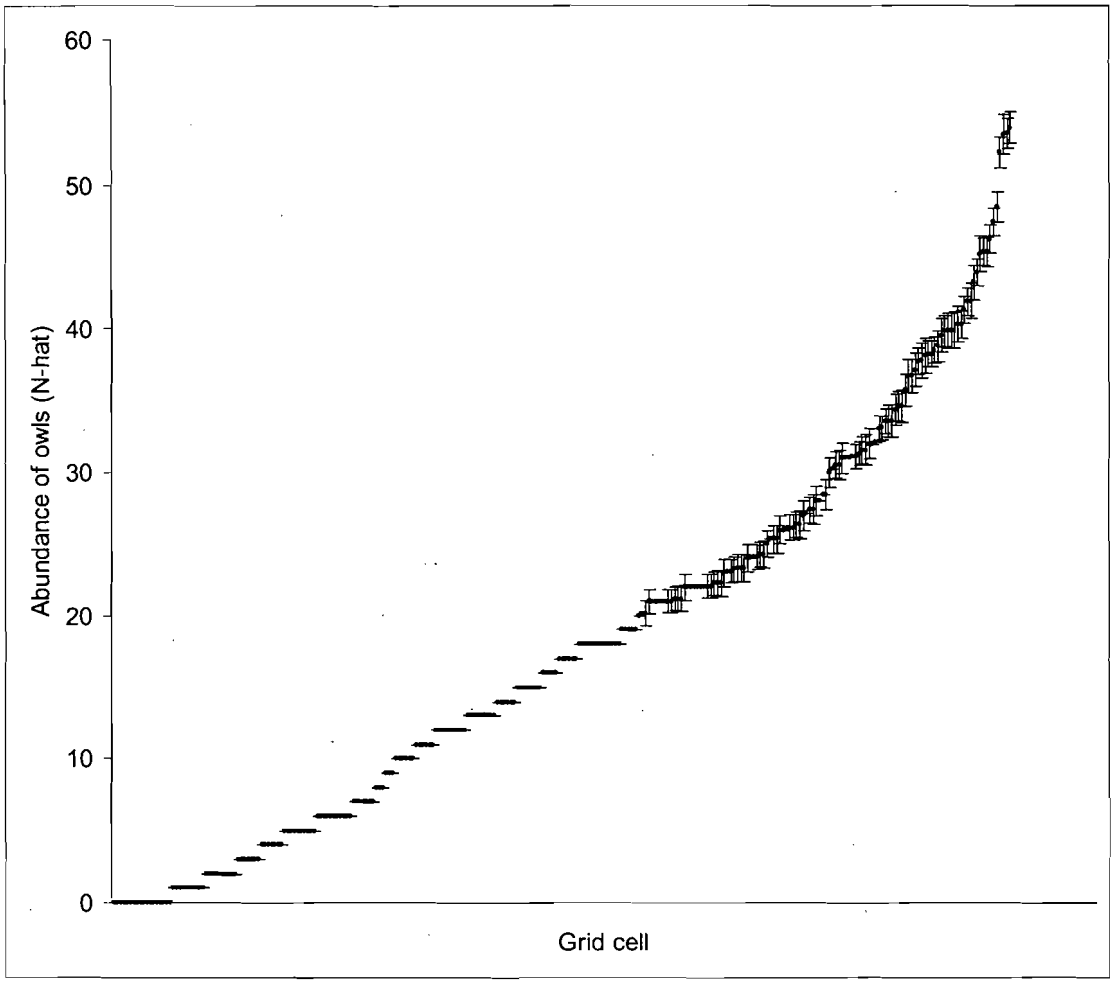


Figure 10.1. Estimates of local male Burrowing Owl territory abundances in 3x3 Km grid cells in the HCP Study Area, Imperial County, California, 2007. Data are presented according to increased abundances. Vertical bars are standard errors.

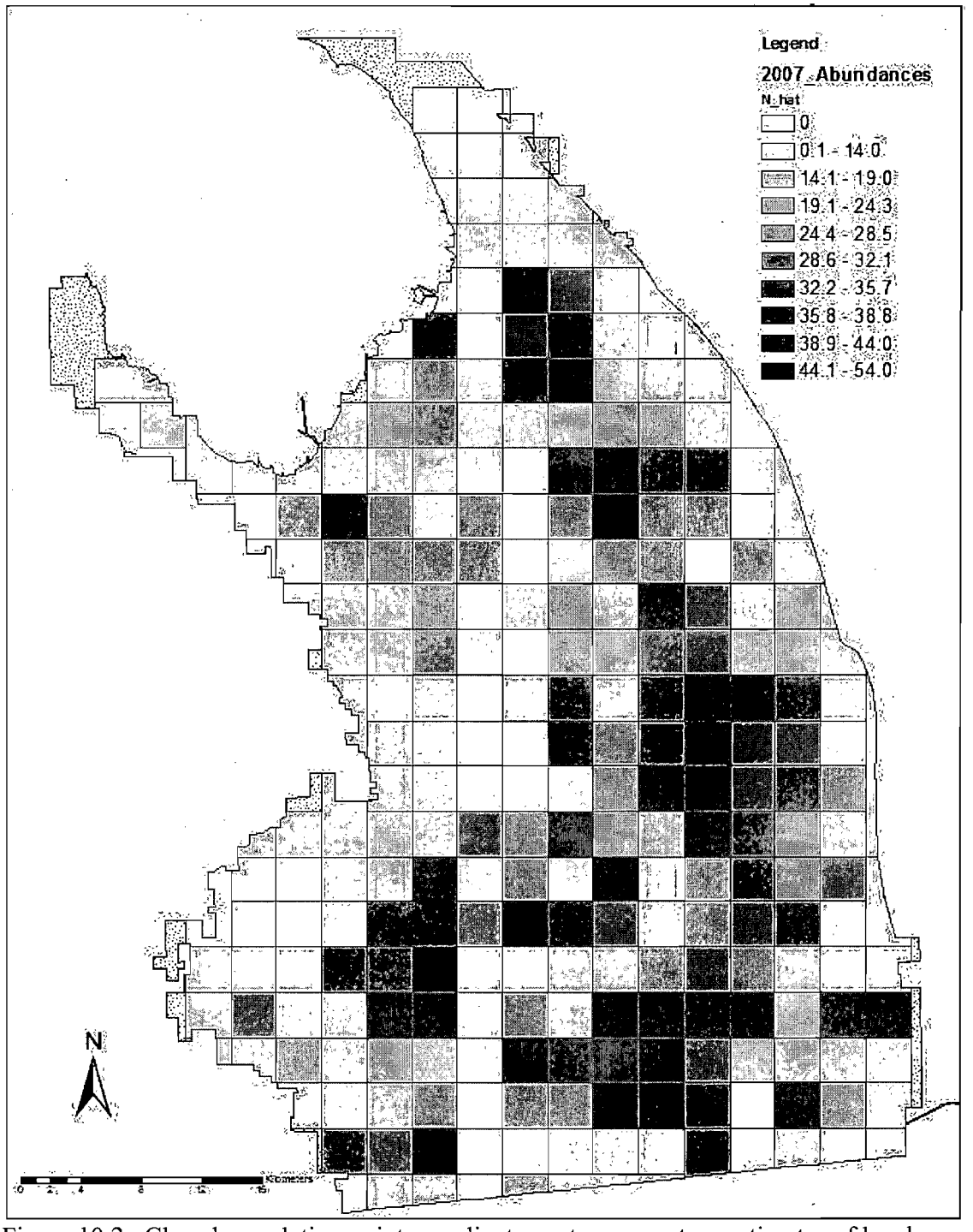


Figure 10.2. Closed-population point-coordinate capture-recapture estimates of local male Burrowing Owl territory abundance in 3x3 km grid cells in the HCP Study Area, Imperial County, California, April 2007. Stippled areas were not surveyed due to the absence of above-ground water conveyance structures.

Chapter 11

DATASETS OF POTENTIAL CORRELATES OF LOCAL MALE BURROWING OWL TERRITORY ABUNDANCE IN 2007

JEFFREY A. MANNING

ABSTRACT. Knowledge of potential environmental correlates of Burrowing Owl abundance is important in the development of survey protocols because using such correlates to stratify the HCP Study Area prior to future surveys could reduce logistical effort and costs by improving the precision of population estimates. Here, I describe spatial datasets of environmental and biological variables intended for comparing their individual and additive potential as correlates of local male Burrowing Owl territory abundance. These datasets included soils, IID maintenance activities, number of suitable nesting burrows, type of water conveyance structure, and agricultural crops.

INTRODUCTION

The identification of factors (i.e., habitat characteristics and IID maintenance activities) that may be suitable correlates of Burrowing Owl abundance was based on existing biological information and on availability of data that extends across the HCP Study Area. The latter basis was important because the intended purpose of suitable correlates was to stratify the HCP Study Area in order to optimally allocate future annual survey efforts. Thus, suitable correlates must be measurable and available across the entire HCP Study Area each year prior to conducting owl surveys.

Several factors have been hypothesized as important correlates of Burrowing Owl nest burrows, and hence possibly abundance of male territories. These include soils, maintenance activities, sympatric fossorial (burrowing) mammals, surrounding vegetation (in the HCP Study Area, this referred largely to agricultural crops), and type of bank (cement-lined or earthen) along water conveyance structures. We obtained data on each one of these factors in order to incorporate them into our analyses to test for their relative importance in predicting owl abundance

METHODS

Soils

Soft, friable, loamy soils have been hypothesized to be an important correlate of Burrowing Owl nest burrows (MacCracken et al. 1985, Green 1983). Thus, soils that deviate from this soil type are anticipated to coincide with fewer numbers of owls.

Soil information was obtained from the USDA Natural Resource Conservation Service (NRCS) geodatabase of soils (NRCS 2005). These data were derived from a digital soil survey developed by the National Cooperative Soil Survey, and was the most detailed

level of soil geographic data available. It was prepared by digitizing maps, compiling information onto a planimetric-correct base and digitizing from it, and/or revising digitized maps using remotely sensed information (NRCS 2005). National Cooperative Soil Survey standards and procedures were used in the classification of soils, design and name of map units, and location of special soil features in this dataset (NRCS 1993, NRCS 1995, NRCS and NSS undated current issue).

These data were clipped from: "Categorical ranking of soils in the Imperial Valley," California according to their suitability for burrowing owls. We measured the following soil classes in each 3x3 km grid cell for use as correlates (Figure 11.1):

1. proportion of poorly suited soils (continuous variable)
2. proportion of suitable soils (continuous variable)
3. proportion of well suited soils (continuous variable)
4. proportion of suitable and well suited soils (continuous variable)
5. dominant soil class (poorly suited, suitable, well suited; ordinal variable)

Imperial Irrigation District's maintenance activities

Section 4.5.2.2 of the HCP specified that "the Burrowing Owl population data will be linked to or combined with spatial information on the IID's maintenance activities..." This is because maintenance of water conveyance structures (i.e., dredging) is believed to possibly affect nest burrows. Thus, the location, year, and type of maintenance activities should also be assessed as possible determinants of owl abundance.

I met with maintenance personnel at the IID in April 2007 and obtained Microsoft Excel spreadsheets and GIS vector features of maintenance activities that occurred over the past 4 years. In most cases, the data were not detailed (e.g., not specific to a location on a canal, but rather named the entire canal, or a general definition for a maintenance activity was used). I counted the frequency of specific maintenance activities performed by the Imperial Irrigation District along irrigation canal and drain right-of-ways within each 3x3 km grid cell by year. Original drain and canal data were obtained by CH2M Hill, Sacramento, California. These data were further reduced to 12 general types of maintenance activity that were anticipated to possibly impact burrowing owls (as classified by the IID):

1. W03 = Concrete lined channel repair
2. W04 = Concrete lined channel brush and weed control by machine
3. W06 = Drain brush and weed control by machine
4. W08 = Earth channel machine clearing
5. W11 = Concrete canal structure maintenance
6. W12 = Drain structure maintenance
7. W13 = Earth canal structure maintenance
8. W17 = Concrete channel bank maintenance-road grading
9. W18 = Drain bank maintenance-road grading
10. W19 = Earth channel bank maintenance-road grading

11. W28 = Flood control
12. W29 = Pipeline maintenance

These general types of activities were summed for each canal or drain (vector), and divided by the total length of that water conveyance structure (across grid cells); this was multiplied by the total length of that structure in each cell, and summed across all water conveyance structures in the cell to produce grid cell-level estimates (Figure 11.2).

Availability of potential nest burrows

The presence of sympatric, fossorial mammals has been identified as an important correlate of Burrowing Owl nests (Thomsen 1971, Martin 1973, Zarn 1974, Wedgwood 1978, Haug 1985, Haug et al. 1993, Klute et al. 2003). This is because Burrowing Owls depend on the burrows from these mammals for nesting. Various species of fossorial mammals occupy the HCP Study Area, including the California ground squirrel (*Spermophilus beecheyi*), round tailed ground squirrel (*Spermophilus tereticaudus*), and Antelope ground squirrel (*Ammospermophilus leucurus*). The number of burrows dug by these mammals along the IID's right-of-way may be suitable for predicting the abundance of owl territories.

A complete count of burrows that were 'potentially suitable' as nest burrows for Burrowing Owls was conducted along the IID's rights-of-way. A burrow/hole was considered to be potentially suitable if it entered into an earthen surface, space within a debris pile, or pipe with an entrance between 3.5-15 inches in diameter that was flush with the ground. All burrows/holes that met this criteria were counted, even if occupied by a small mammal, and burrows/holes <20 m apart were considered as a single count because these data were intended to predict the number of male Burrowing Owl territories, and a single Burrowing Owl can occupy such a complex.

Vehicle-based surveys for potential burrows were completed from March 23-27, 2007, days before capture-recapture surveys were conducted for Burrowing Owls, following these procedures:

1. An observer and driver surveyed by vehicle
2. Vehicles were positioned so observers were closest to drains/canals
3. Traveled at 10 mph
4. Observers visually detected burrows while traveling in the vehicle, and used a handheld tally counter to record the number of burrows/complexes.
5. Observers set the Trimble GeoExplorer XM to record continuous vectors in order to map linear segments of the IID's right-of-way traveled in association with burrow counts.
6. Vehicles stopped every 0.5 miles to discontinue recording each previous vector, recorded the number of tallied burrows in the Trimble GeoExplorer XM data dictionary for each vector.

I summed the tallied number of burrows in each 0.5-mile within each 3x3 km grid cell in the GIS layer (Figure 11.3), and considered this summed count as a continuous variable in our correlative analyses of Burrowing Owl abundance.

Surrounding agricultural crops

The type of vegetation surrounding Burrowing Owl nest burrows may be correlated with abundance of male territories (Rich 1986, Green and Anthony 1989, Haug and Oliphant 1990, Plumpton and Lutz 1993), and thus may aid in predicting the abundance of owls across the HCP Study Area. For example, an intensive radio-tracking study of a small sample of owls in the Imperial Valley found 9 crop types were used, and that owls selected for barren ground near (<1,980 ft) and hay far (>1,980 ft) from nests (Rosenberg and Haley 2004). Furthermore, section 4.5.2.2 specified that "the burrowing owl population data will be linked to or combined with spatial information on ... crop types in the HCP Study Area."

Relating crops to Burrowing Owl abundance is challenged by how and when owls tend to establish and maintain territories. Like many raptors, Burrowing Owls tend to establish territories and then occupy them for years, barring no major disturbances or nest failures. This complicates using current crop information to predict the current distribution of owl abundance because abundances may have been due to crop types present in the past. For example, older owls in the current population likely selected their territories farther back in the past than younger owls. If older owls represent the larger age class in the current population, and may have selected sites based on crops that are not currently present at those sites, a pattern between current crops and current owl abundance across the HCP Study Area may not emerge. In the absence of demographic data, methods to ascertain patterns between crops and current estimates of owl abundance warrant a multiple working hypotheses (Chamberlin 1890, 1965) approach based on comparisons of annual crop information (e.g., over the previous 5 years) and local estimates of abundance across the current Burrowing Owl population.

I took a retrospective approach to determine what crop(s) and how many years in the past the dominant age class in the current owl population may have selected their territories. If successful, this method could also possibly provide an indirect measure of the dominant age class in the Burrowing Owl population during the 2007 owl surveys. It may also be valuable in identifying the type of crop and how many years previous from a proposed population survey crops should be examined in order to adequately stratify the HCP Study Area and efficiently allocate survey efforts over the 75-year HCP permit.

This remote classification of the agricultural crops is presented separately in Appendix III. Here, those results were further used to assign a crop-related value to each 3x3 km grid cell separately each year. I computed the richness (number) of unique crops in a grid cell, and the proportion of each grid cell in the following cover types (Figure 11.4):

1. Level II grass
2. Level II bare ground and fallow

3. Level II broadleaf
4. wheat
5. fallow
6. Sudan
7. alfalfa
8. Bermuda
9. bare ground

These specific cover types were chosen because of their suggested importance in the literature (e.g., Rosenberg and Haley 2004) or expected similarity to those suggested to be important.

Type of water conveyance structure bank

Abundance of owl nests is anticipated to differ between canals, drains, and interceptors (Rosenberg and Haley 2004). Because a single or combination of these water conveyance structure(s) can occur within any stretch of the IID's rights-of-way, I had initially proposed to assign one of up to 10 different categories to each right-of-way. After reviewing the IID's canal and drain GIS feature layers, I was able only to assign only 2 categories (cement lined or earthen). I used these data to assign the proportion of cement-lined right-of-way to each 3x3 km grid cell (Figure 11.5).

RESULTS

The following figures display the GIS-based spatial datasets of selected environmental variables intended for use in assessing their potential as correlates of Burrowing Owl abundance.

CONCLUSIONS AND RECOMMENDATIONS

The resulting datasets were used in the following chapter to assess their relative importance as correlates of male Burrowing Owl territory abundance.

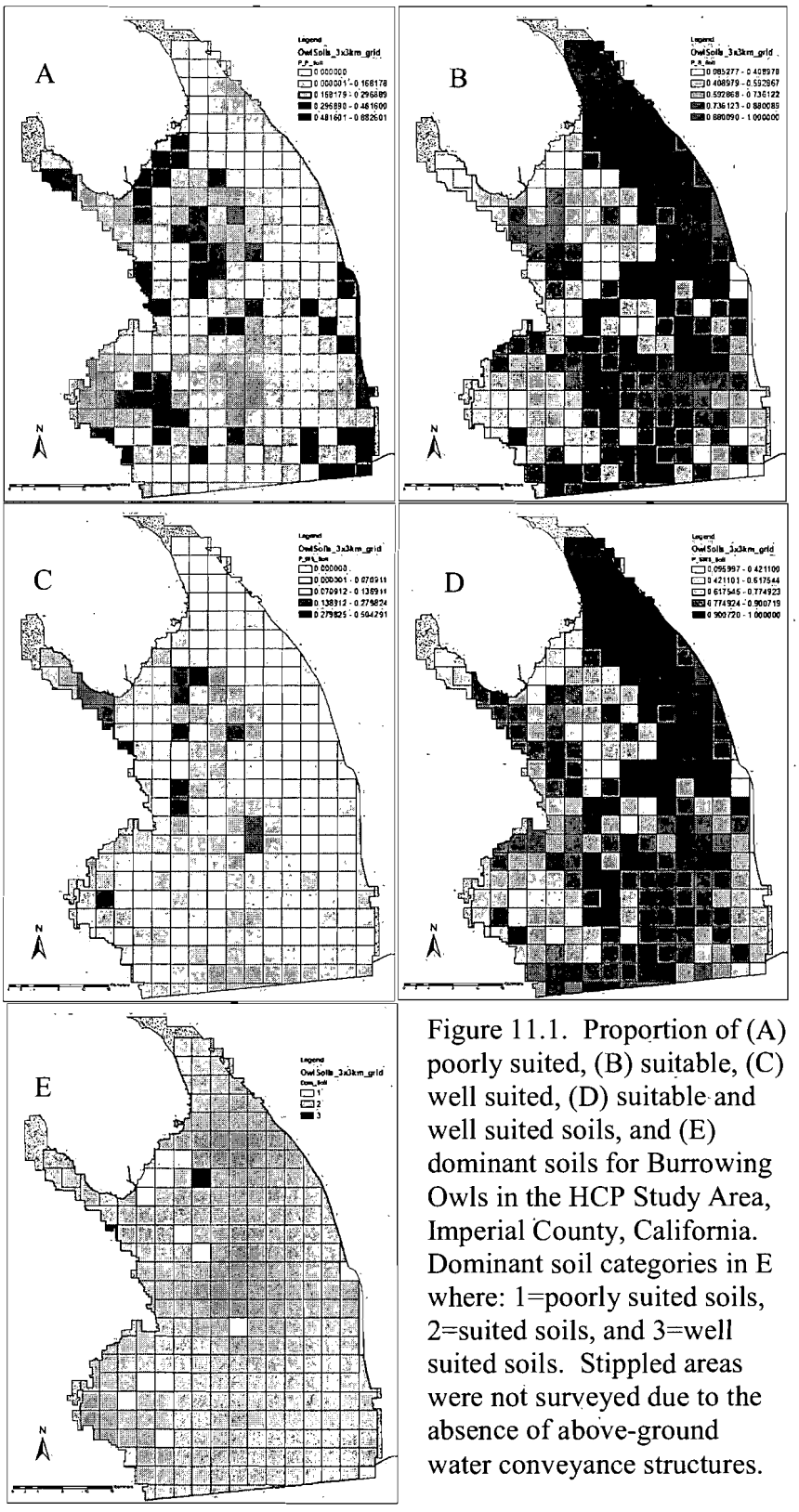


Figure 11.1. Proportion of (A) poorly suited, (B) suitable, (C) well suited, (D) suitable and well suited soils, and (E) dominant soils for Burrowing Owls in the HCP Study Area, Imperial County, California. Dominant soil categories in E where: 1=poorly suited soils, 2=suited soils, and 3=well suited soils. Stippled areas were not surveyed due to the absence of above-ground water conveyance structures.

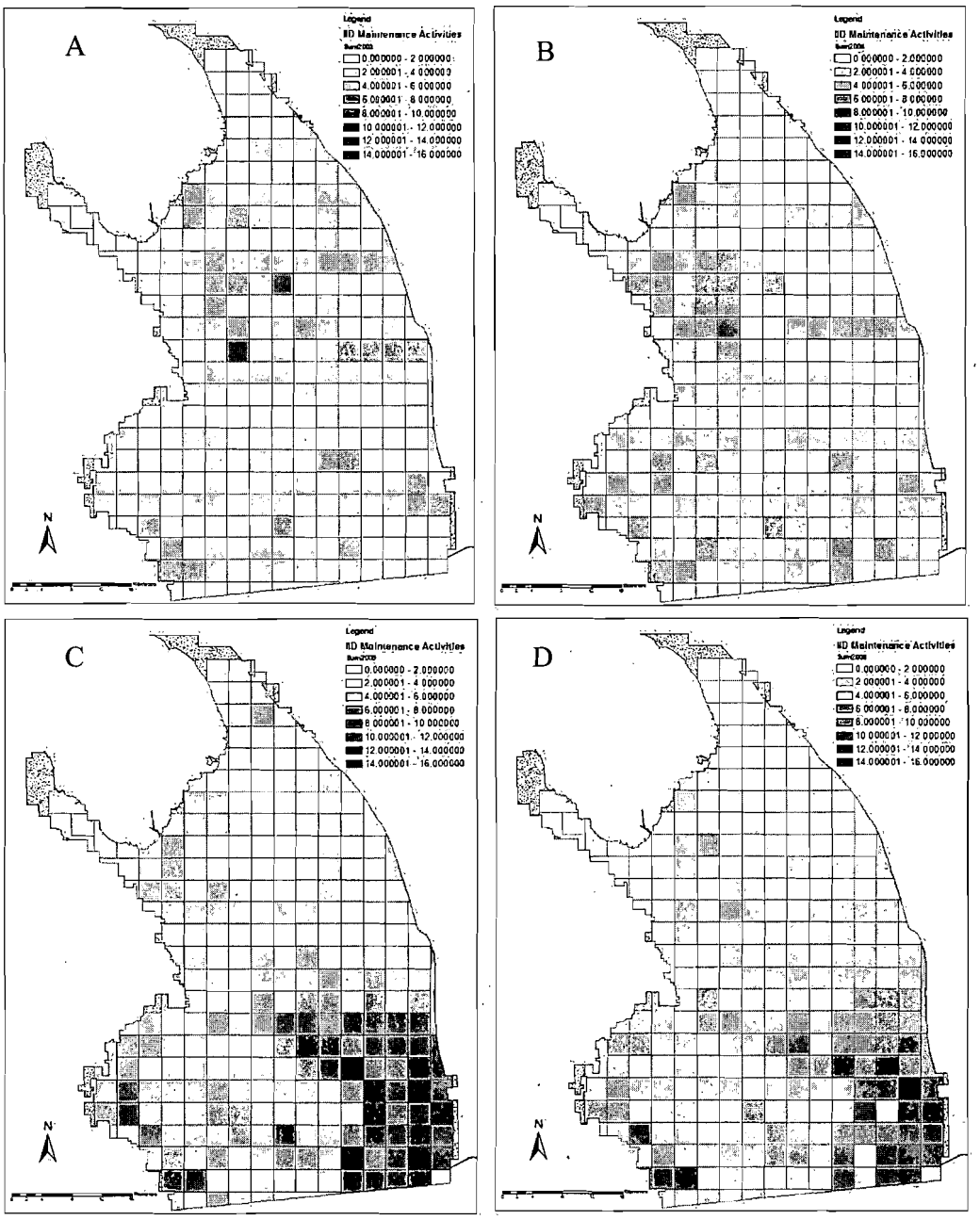


Figure 11.2. Frequency of the IID's maintenance activities in (A) 2003, (B) 2004, (C) 2005, and (D) 2006, Imperial County, California. Stippled areas were not surveyed due to the absence of above-ground water conveyance structures.

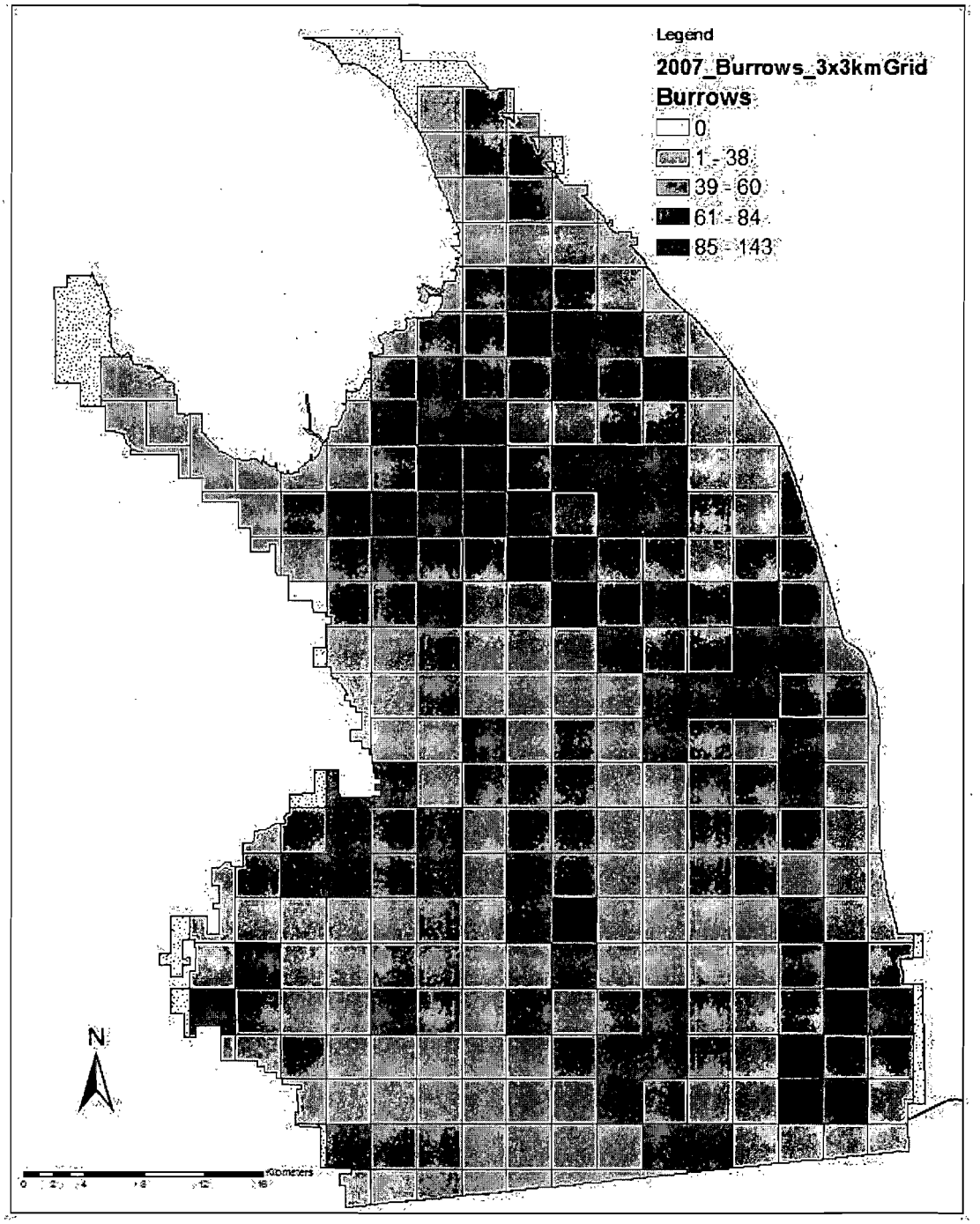


Figure 11.3. Number of potential Burrowing Owl nest burrows in the HCP Study Area, Imperial County, California, April 2007. Stippled areas were not surveyed due to absence of above-ground water conveyance structures.

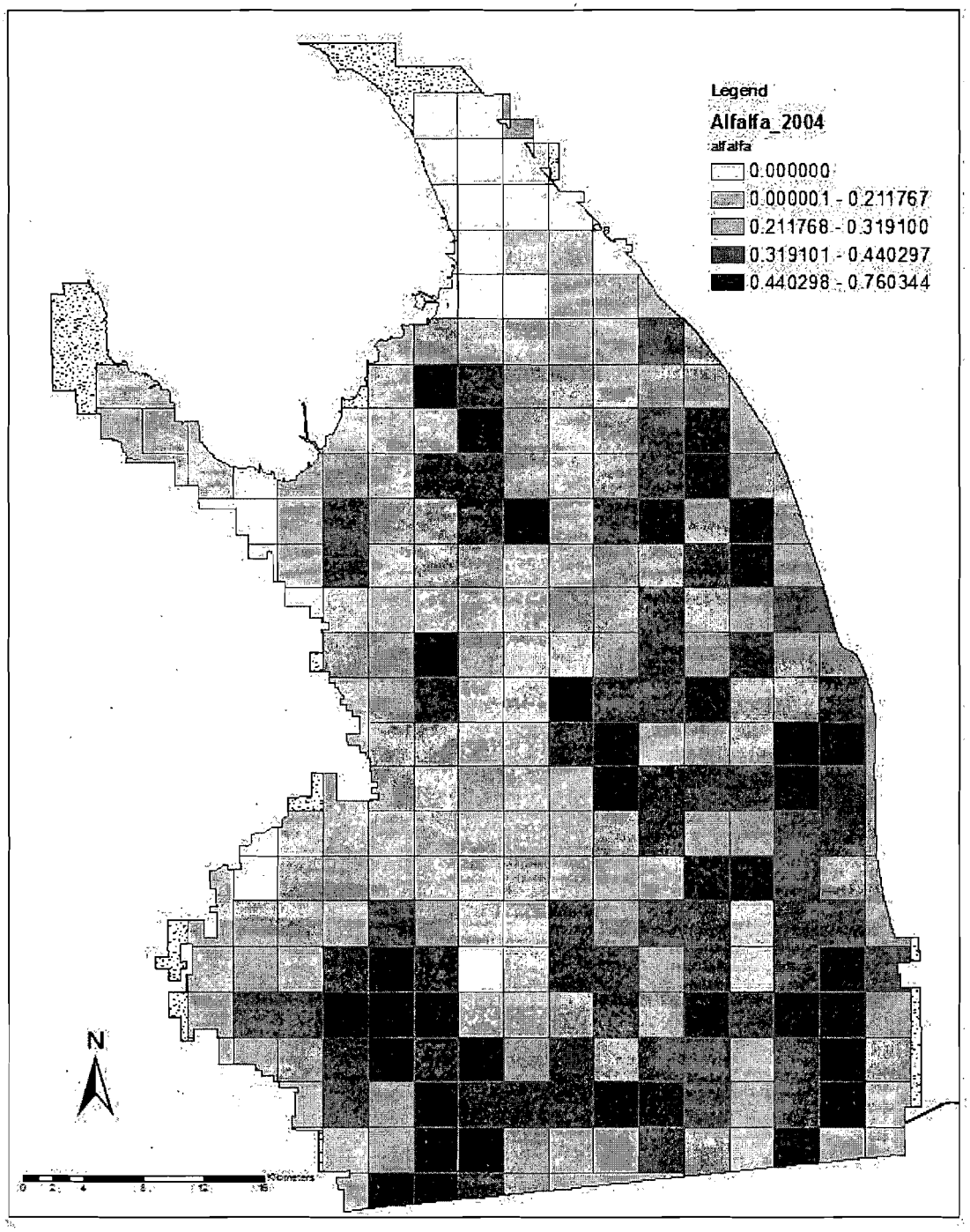


Figure 11.4. Proportion of crop class level III alfalfa in the HCP Study Area, Imperial County, California, 2004. This figure also is representative of the numerous other crop datasets generated. Stippled areas were not surveyed due to absence of above-ground water conveyance structures.

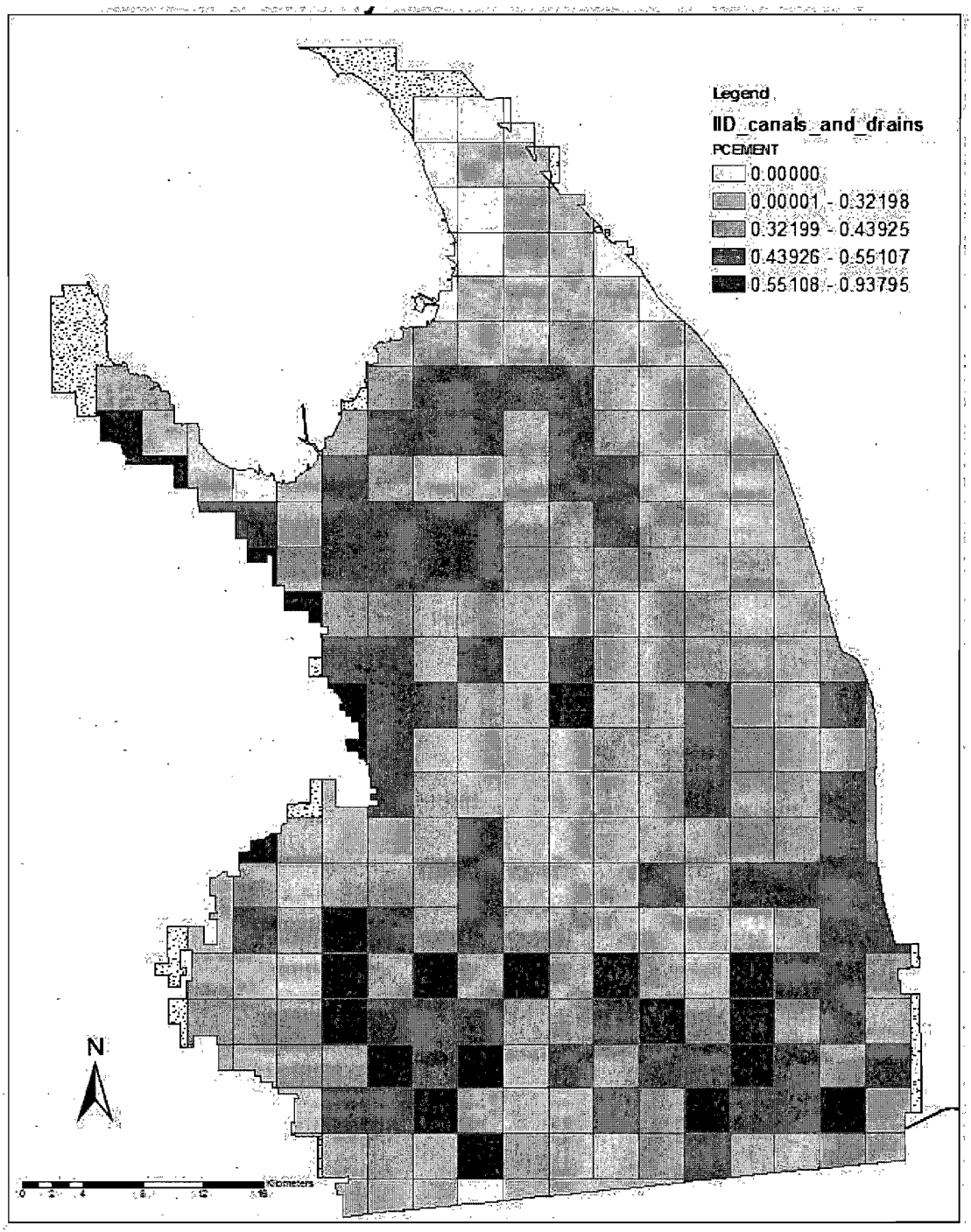


Figure 11.5. Percent cement-lined IID water conveyance structures, Imperial Valley, California, 2007. Stippled areas were not surveyed due to absence of above-ground water conveyance structures.

Chapter 12

THE RELATIVE IMPORTANCE OF POTENTIAL CORRELATES OF MALE BURROWING OWL TERRITORY ABUNDANCE

JEFFREY A. MANNING AND CAREN S. GOLDBERG

ABSTRACT. Given the large number of potential correlate datasets of Burrowing Owl abundance presented in the previous chapter, it is advantageous to assess their relative importance as correlates in order to consider only the strongest correlate(s). Here, we present modeling results from evaluating the relative importance of the potential correlates of male Burrowing Owl territory abundance in 2007. We intended that the resulting correlative model could be used to estimate the abundance of owls from its surrogate variable(s) reasonably well enough to stratify the sampling grid according to broad ranges of abundance because stratification would aid in improving the accuracy of sample estimates of abundance. We used the information theoretic approach with multiple-working hypotheses to compare 74 models, where each model represented one of the working hypotheses. The best model predicted male Burrowing Owl territory abundance as a function of the linear length of IID water conveyance structure, available burrows in 2007, and the proportion of agricultural crops in alfalfa production in 2004. We found that spatial autocorrelation was significant up to 2 nearest grid cell neighbors out, and a spatial covariate term added to the model improved the model's predictive ability.

INTRODUCTION

An important part of the long-term stratified random sampling survey method we proposed is to produce a model with environmental variables that can be used in subsequent years to determine which strata (low, medium, and high abundances of male Burrowing Owl territories) a grid cell belongs to prior to a given population survey. This stratification would be used to randomly select grid cells to be surveyed. Due to the dynamic nature of the system in the HCP Study Area, the use of this model to assign grid cells to specific strata is designed for re-stratifying grid cells each year.

Our objective here was to develop a model, using the environmental variables gathered and presented in Chapter 11, of the relative best correlates of male Burrowing Owl territory abundance in the HCP Study Area. We chose to use the estimate of local abundance in each independent sampling unit from Chapter 10 as the response variable in linear models outside of a closed-population statistical platform (e.g., program MARK; Cooch 1999, White and Burnham 1999) because the optimal allocation of effort proposed under our stratified random sampling approach required a large number of standardized sampling units (274 grid cells). This large number of units would lead to over-parameterized models in such platforms. Furthermore the extrapolation of results from future stratified random sampling to a full population estimate is currently unavailable within such a platform.

METHODS

Each single or combination of correlate(s) constituted a hypothesis represented by a statistical model, with owl abundance as the response, based on the 3x3 km grid as sampling units. Because the error surrounding each abundance estimate was expected not to be constant, we fit weighted least square regression models (Cleveland 1979, Cleveland and Devlin 1988) to the data. Weighted least squares regression is an efficient method to provide easily interpretable statistical intervals for estimation, prediction, calibration and optimization. In addition, the main advantage that the weighted least squares method has over other methods is the ability to handle regression situations where the data points vary in quality. If the variance of the random errors in the data is not constant across all levels of the explanatory variable(s), the use of weighted least squares can yield relatively precise parameter estimates.

Model structures followed that of simple linear regression (Table 12.1). We restricted additive structures to those factors that have been shown or suggested to be important for Burrowing Owls (e.g., alfalfa, bare ground, and fallow fields; Rosenberg and Haley 2004). Because the Burrowing Owl abundance data in each cell were dependent on the linear length of IID-maintained water conveyance structures, we standardized this effect by including a term for linear length of these structures as the baseline in every model we fit to the data. The inclusion of this variable in all models precluded the need to scale other explanatory variables by linear length of water conveyance structures.

We compared the relative fit of each model following a multiple-hypothesis testing framework, based a model-selection procedure with AIC (Akaike 1973). This information theoretic approach (Burnham and Anderson 2002) was intended to determine the best correlates of male Burrowing Owl territory abundance that we measured by identifying the most parsimonious model. Such correlates are necessary to develop strata classes associated with low, medium, and high abundances of male Burrowing Owl territories in the HCP Study Area for the development of a long-term sampling methodology.

We tested for spatial autocorrelation in the residuals of the best model using the Moran's *I* spatial statistic in Program Geoda95 (Spatial Analysis Laboratory, University of Illinois, Urbana-Champaign, IL). This test was used to assess spatial autocorrelation in owl abundance that explanatory variables did not account for in the model. We used a weight matrix based on Queen's adjacency scheme to identify how far out from a given cell (i.e., to what degree of neighboring cells) abundance was autocorrelated. We then accounted for this spatial covariance structure by using this distance to incorporate a term in the best model, thereby allowing the model to estimate the spatial coefficient, which is similar to methods used with mixed models (Laird and Ware 1982). This approach was recommended by Dr. Bryan Manly in his letter, dated June 5, 2007. We considered this model, which included the spatial autocorrelation term, as our 'best' model.

We validated the assumptions underlying the best model by performing graphical analyses of residuals. We plotted the innermost fitted values from the best model against

observed values of the response variable to provide an overall summary of explanatory power of the model, how much variation is explained, how much remains, and evidence of lack of fit. We also plotted the innermost fitted values against the innermost residuals to assess the assumption of correct model structure.

We also used a version of *k*-fold cross validation [leave-one-out cross validation; Devijver and Kittler (1982)] to validate how well the model parameters from our best model could predict abundance in a grid cell. This validation approach involved using a single observation from the original sample as the validation data, and the remaining observations as the training data. This was repeated such that each observation in the sample was used once as the validation data. We performed these analyses in Program R (Ihaka and Gentleman 1996).

Table 12.1. Linear regression models (presented as program R code). Model names are to the left of '<-' and refer to a model's explanatory variables. Definitions of model syntax are provided at the bottom of the table.

```
03grass.lm <- lm(Nhat ~ TotLength + 03grass, data=buow, weights=Nhatwt)
03barefallow.lm <- lm(Nhat ~ TotLength + 03barefallow, data=buow, weights=Nhatwt)
03broadleaf.lm <- lm(Nhat ~ TotLength + 03broadleaf, data=buow, weights=Nhatwt)
04grass.lm <- lm(Nhat ~ TotLength + 04grass, data=buow, weights=Nhatwt)
04barefallow.lm <- lm(Nhat ~ TotLength + 04barefallow, data=buow, weights=Nhatwt)
04broadleaf.lm <- lm(Nhat ~ TotLength + 04broadleaf, data=buow, weights=Nhatwt)
05grass.lm <- lm(Nhat ~ TotLength + 05grass, data=buow, weights=Nhatwt)
05barefallow.lm <- lm(Nhat ~ TotLength + 05barefallow, data=buow, weights=Nhatwt)
05broadleaf.lm <- lm(Nhat ~ TotLength + 05broadleaf, data=buow, weights=Nhatwt)
06grass.lm <- lm(Nhat ~ TotLength + 06grass, data=buow, weights=Nhatwt)
06barefallow.lm <- lm(Nhat ~ TotLength + 06barefallow, data=buow, weights=Nhatwt)
06broadleaf.lm <- lm(Nhat ~ TotLength + 06broadleaf, data=buow, weights=Nhatwt)
07grass.lm <- lm(Nhat ~ TotLength + 07grass, data=buow, weights=Nhatwt)
07barefallow.lm <- lm(Nhat ~ TotLength + 07barefallow, data=buow, weights=Nhatwt)
07broadleaf.lm <- lm(Nhat ~ TotLength + 07broadleaf, data=buow, weights=Nhatwt)
03wheat.lm <- lm(Nhat ~ TotLength + 03wheat, data=buow, weights=Nhatwt)
03fallow.lm <- lm(Nhat ~ TotLength + 03fallow, data=buow, weights=Nhatwt)
03sudan.lm <- lm(Nhat ~ TotLength + 03sudan, data=buow, weights=Nhatwt)
03alfalfa.lm <- lm(Nhat ~ TotLength + 03alfalfa, data=buow, weights=Nhatwt)
03bermuda.lm <- lm(Nhat ~ TotLength + 03bermuda, data=buow, weights=Nhatwt)
03bareground.lm <- lm(Nhat ~ TotLength + 03bareground, data=buow, weights=Nhatwt)
04wheat.lm <- lm(Nhat ~ TotLength + 04wheat, data=buow, weights=Nhatwt)
04fallow.lm <- lm(Nhat ~ TotLength + 04fallow, data=buow, weights=Nhatwt)
04sudan.lm <- lm(Nhat ~ TotLength + 04sudan, data=buow, weights=Nhatwt)
04alfalfa.lm <- lm(Nhat ~ TotLength + 04alfalfa, data=buow, weights=Nhatwt)
04bermuda.lm <- lm(Nhat ~ TotLength + 04bermuda, data=buow, weights=Nhatwt)
04bareground.lm <- lm(Nhat ~ TotLength + 04bareground, data=buow, weights=Nhatwt)
05wheat.lm <- lm(Nhat ~ TotLength + 05wheat, data=buow, weights=Nhatwt)
05fallow.lm <- lm(Nhat ~ TotLength + 05fallow, data=buow, weights=Nhatwt)
05sudan.lm <- lm(Nhat ~ TotLength + 05sudan, data=buow, weights=Nhatwt)
05alfalfa.lm <- lm(Nhat ~ TotLength + 05alfalfa, data=buow, weights=Nhatwt)
05bermuda.lm <- lm(Nhat ~ TotLength + 05bermuda, data=buow, weights=Nhatwt)
05bareground.lm <- lm(Nhat ~ TotLength + 05bareground, data=buow, weights=Nhatwt)
06wheat.lm <- lm(Nhat ~ TotLength + 06wheat, data=buow, weights=Nhatwt)
06fallow.lm <- lm(Nhat ~ TotLength + 06fallow, data=buow, weights=Nhatwt)
06sudan.lm <- lm(Nhat ~ TotLength + 06sudan, data=buow, weights=Nhatwt)
06alfalfa.lm <- lm(Nhat ~ TotLength + 06alfalfa, data=buow, weights=Nhatwt)
06bermuda.lm <- lm(Nhat ~ TotLength + 06bermuda, data=buow, weights=Nhatwt)
06bareground.lm <- lm(Nhat ~ TotLength + 06bareground, data=buow, weights=Nhatwt)
```

```
07wheat.lm <- lm(Nhat ~ TotLength + 07wheat, data=buow, weights=Nhatwt)
07fallow.lm <- lm(Nhat ~ TotLength + 07fallow, data=buow, weights=Nhatwt)
07sudan.lm <- lm(Nhat ~ TotLength + 07sudan, data=buow, weights=Nhatwt)
07alfalfa.lm <- lm(Nhat ~ TotLength + 07alfalfa, data=buow, weights=Nhatwt)
07bermuda.lm <- lm(Nhat ~ TotLength + 07bermuda, data=buow, weights=Nhatwt)
07bareground.lm <- lm(Nhat ~ TotLength + 07bareground, data=buow, weights=Nhatwt)
03CrpRch.lm <- lm(Nhat ~ TotLength + 03CrpRch, data=buow, weights=Nhatwt)
04CrpRch.lm <- lm(Nhat ~ TotLength + 04CrpRch, data=buow, weights=Nhatwt)
05CrpRch.lm <- lm(Nhat ~ TotLength + 05CrpRch, data=buow, weights=Nhatwt)
06CrpRch.lm <- lm(Nhat ~ TotLength + 06CrpRch, data=buow, weights=Nhatwt)
07CrpRch.lm <- lm(Nhat ~ TotLength + 07CrpRch, data=buow, weights=Nhatwt)
03IIDMnt.lm <- lm(Nhat ~ TotLength + 03IIDMnt, data=buow, weights=Nhatwt)
04IIDMnt.lm <- lm(Nhat ~ TotLength + 04IIDMnt, data=buow, weights=Nhatwt)
05IIDMnt.lm <- lm(Nhat ~ TotLength + 05IIDMnt, data=buow, weights=Nhatwt)
06IIDMnt.lm <- lm(Nhat ~ TotLength + 06IIDMnt, data=buow, weights=Nhatwt)
TotIIDMnt.lm <- lm(Nhat ~ TotLength + TotIIDMnt, data=buow, weights=Nhatwt)
PPSoil.lm <- lm(Nhat ~ TotLength + PPSoil, data=buow, weights=Nhatwt)
PSSoil.lm <- lm(Nhat ~ TotLength + PSSoil, data=buow, weights=Nhatwt)
PWSoil.lm <- lm(Nhat ~ TotLength + PWSoil, data=buow, weights=Nhatwt)
PSWSoil.lm <- lm(Nhat ~ TotLength + PSWSoil, data=buow, weights=Nhatwt)
DomSoil.lm <- lm(Nhat ~ TotLength + DomSoil, data=buow, weights=Nhatwt)
07Brrws.lm <- lm(Nhat ~ TotLength + 07Brrws, data=buow, weights=Nhatwt)
PCementlined.lm <- lm(Nhat ~ TotLength + PCementlined, data=buow, weights=Nhatwt)
TotLength.lm <- lm(Nhat ~ TotLength, data=buow, weights=Nhatwt)

07Brrwsplus03alfalfa.lm <- lm(Nhat ~ TotLength + 07Brrws + 03alfalfa, data=buow, weights=Nhatwt)
07Brrwsplus04alfalfa.lm <- lm(Nhat ~ TotLength + 07Brrws + 04alfalfa, data=buow, weights=Nhatwt)
07Brrwsplus05alfalfa.lm <- lm(Nhat ~ TotLength + 07Brrws + 05alfalfa, data=buow, weights=Nhatwt)
07Brrwsplus06alfalfa.lm <- lm(Nhat ~ TotLength + 07Brrws + 06alfalfa, data=buow, weights=Nhatwt)
07Brrwsplus07alfalfa.lm <- lm(Nhat ~ TotLength + 07Brrws + 07alfalfa, data=buow, weights=Nhatwt)

07Brrwsplus03barefallow.lm <- lm(Nhat ~ TotLength + 07Brrws + 03barefallow, data=buow, weights=Nhatwt)
07Brrwsplus04barefallow.lm <- lm(Nhat ~ TotLength + 07Brrws + 04barefallow, data=buow, weights=Nhatwt)
07Brrwsplus05barefallow.lm <- lm(Nhat ~ TotLength + 07Brrws + 05barefallow, data=buow, weights=Nhatwt)
07Brrwsplus06barefallow.lm <- lm(Nhat ~ TotLength + 07Brrws + 06barefallow, data=buow, weights=Nhatwt)
07Brrwsplus07barefallow.lm <- lm(Nhat ~ TotLength + 07Brrws + 07barefallow, data=buow, weights=Nhatwt)
```

Bareground referred to the proportion of a grid in a bare ground condition (i.e., no vegetation), barefallow was the proportion of a grid cell in a bare ground and fallow conditions, CrpRch was crop richness (count) in a grid cell, Brrws was the number of suitable burrows counted in a grid cell in 2007 immediately prior to the population surveys, PCementlined was the proportion of above-ground water conveyance structure in a grid cell that was cement-lined, TotLength was the total length of above-ground water conveyance structure in a grid cell, and IIDMnt was the frequency of IID's maintenance activities in a grid cell (as calculated in the previous chapter). Numeric values preceding model names referred to year.

RESULTS

The best model predicted male Burrowing Owl territory abundance as a function of available burrows in 2007 and the proportion of agricultural crops in alfalfa production in 2004, with the next model having a ΔAIC = 1.62 ($r^2 = 0.37$, $F_{3,270} = 53.7$, $p<0.001$; Tables 12.2 and 12.3). The difference between this model and a competing one was the year of alfalfa production. Because both models had the same number of parameters and alfalfa production between any 2 years is likely to be correlated, we considered the model with the smaller ΔAIC as the best for stratification purposes.

We used the residuals from the best model above to assess spatial autocorrelation in Burrowing Owl abundance, and found that spatial autocorrelation was significant up to 2 nearest grid cell neighbors out (Table 12.4).

We constructed an additional model that included a spatial covariate term that accounted for the mean abundance of male Burrowing Owl territory abundance out to 2 nearest grid cell neighbors away (Table 12.5). The addition of this spatial autocorrelation term improved the fit of the model, with the original model having a ΔAIC = 59.74. The adjusted r^2 for this model was 0.51 ($F_{4,269} = 67.22$, $p<0.001$; Table 12.5), and *k*-fold cross validation indicated that the correlates in the model were not biased (slope in Figure 12.1 = 1) and explained 53% of the variation in grid cells used for validation, which were independent from the cells used for training the model.

Table 12.2. Models of abundance in grid cells and ΔAIC values. All models included the total length of IID water conveyance structure in addition to the parameters listed.

Model Parameters	ΔAIC
Burrows in 2007, alfalfa in 2004	0
Burrows in 2007, alfalfa in 2003	1.62
Burrows in 2007, alfalfa in 2006	5.38
Burrows in 2007, alfalfa in 2005	6.21
Burrows in 2007, bare and fallow in 2007	9.82
Burrows in 2007, bare and fallow in 2006	10.09
Burrows in 2007, bare and fallow in 2003	10.54
Burrows in 2007, bare and fallow in 2004	12.48
Burrows in 2007, alfalfa in 2007	13.16
Burrows in 2007	27.53
Grass in 2006	27.94
Burrows in 2007, bare and fallow in 2005	29.31
Bare/fallow in 2004	30.06
Bermuda grass in 2007	30.46
Alfalfa in 2004	31.03
Alfalfa in 2003	33.29
Fallow in 2007	35.71
Fallow in 2006	40.07
Fallow in 2003	40.19
Grass in 2007	40.70
Alfalfa in 2006	40.92
Bare/fallow in 2007	42.13
Fallow in 2005	43.90
Sudan grass in 2006	43.92
Alfalfa in 2005	44.21
Proportion cement-lined water conveyance structures	44.57
Bare/fallow in 2006	45.14
Bare/fallow in 2003	46.28
Grass in 2004	47.05

Bermuda grass in 2003	47.14
Bare/fallow in 2004	48.13
Grass in 2003	49.01
Broadleaf in 2003	50.27
Bermuda grass in 2004	52.69
Bermuda grass in 2005	52.83
Alfalfa in 2007	52.90
Bermuda in 2006	53.19
Broadleaf in 2004	55.69
Grass in 2005	57.38
IID Mainenence in 2006	58.56
Proportion suitable soils	59.59
Broadleaf in 2006	59.82
Broadleaf in 2007	60.06
Sudan grass in 2004	60.22
Total IID Maintenance activities, 2004-2007	61.14
Proportion suited and well-suited soils	61.39
Wheat in 2004	61.96
Crop richness in 2006	62.03
Wheat in 2003	62.50
Crop richness in 2005	62.52
IID Maintenance in 2005	62.70
Proportion well-suited soils	62.75
Wheat in 2005	63.04
Bare/fallow in 2005	63.87
Crop richness in 2003	64.34
Proportion poorly-suited soils	64.37
Length of water conveyance structures	64.40
Bare ground in 2004	64.60
Dominant soil category	64.69
Crop richness in 2004	64.74
Wheat in 2006	65.01
IID Maintenance in 2004	65.44
Sudan grass in 2003	65.67
Broadleaf in 2005	65.72
Bare ground in 2005	65.72
Sudan Grass in 2007	65.79
Bare ground in 2007	65.83
Wheat in 2007	65.97
IID Maintenance in 2003	66.23
Bare ground in 2006	66.32
Crop richness in 2007	66.35
Bare ground in 2003	66.39

Table 12.3. Summary of best linear regression model without a spatial covariate. TotLength is the total length of IID water conveyance structure (km) in a grid cell, 07Brrws is the number of available burrows counted in a grid cell in 2007, and 04Alfalfa is the proportion of a grid cell covered by alfalfa in the spring 2004.

Parameter	Estimate	Std. Error	*t*-value	Pr(>|t|)
Intercept	-3.63719	2.19056	-1.66	0.09
TotLength	0.45289	0.13106	3.456	<0.001
07Brrws	0.16371	0.02784	5.881	<0.001
04Alfalfa	22.87477	4.12668	5.543	<0.001

Table 12.4. Results from Moran's *I* analysis of spatial autocorrelation, using program GeoDa.

Nearest Neighbors	Moran's *I*	*p*-value
1	0.3011	0.001
2	0.1314	0.001
3	0.0040	0.355

Table 12.5. Summary of best linear regression model with a spatial covariate. TotLength is the total length of IID water conveyance structure (km) in a grid cell, 07Brrws is the number of available burrows counted in a grid cell in 2007, 04Alfalfa is the proportion of a grid cell covered by alfalfa in the spring 2004, and MNhat2NN is the mean abundance of male Burrowing Owl territories out to 2 nearest neighboring grid cells (Queen's rule).

Parameter	Estimate	Std. Error	*t*-value	Pr(>|t|)
Intercept	-12.5436	2.23862	-5.603	<0.001
TotLength	0.27721	0.11923	2.325	0.0208
07Brrws	0.16018	0.02492	6.427	<0.001
04Alfalfa	10.46895	3.9885	2.625	0.009
MNhat2NN	0.83916	0.10177	8.245	<0.001

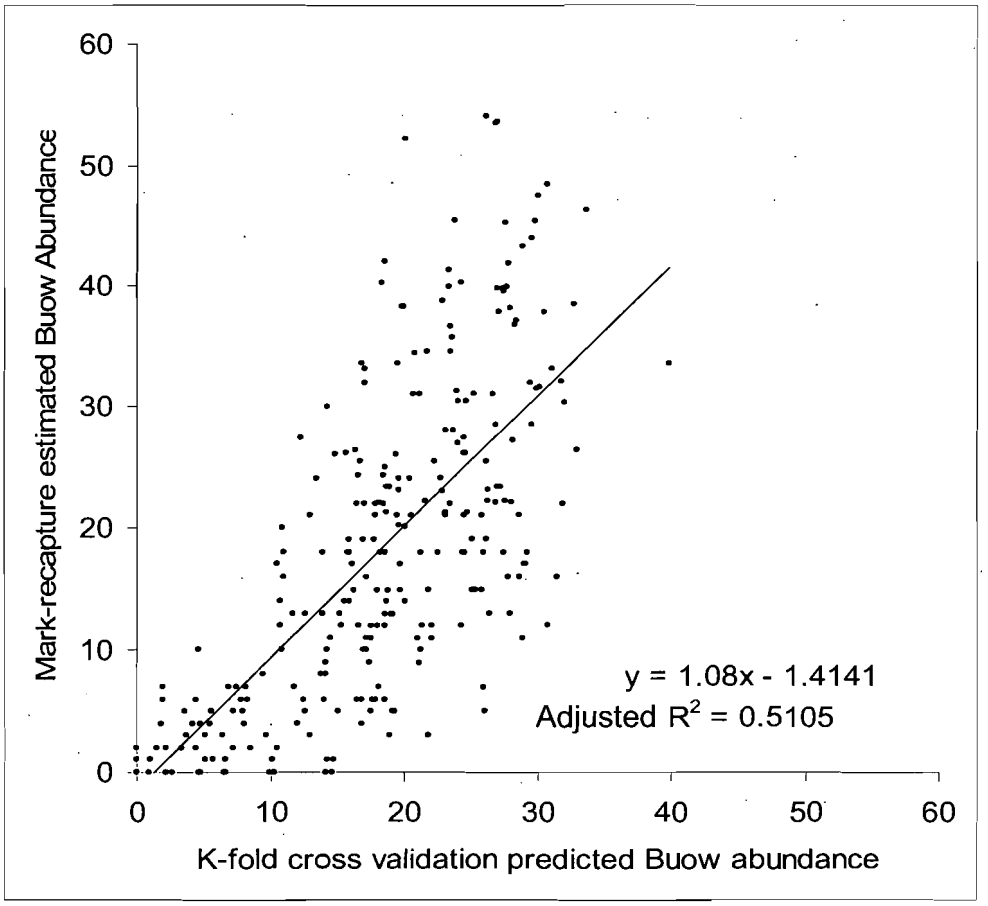


Figure 12.1. Results from *k*-fold cross validation of the best least squares weighted regression with a spatial covariate of owl abundance (Owl territory abundance = TotLength + 07Brrws + 04alfalfa + MNhat2NN) for predicting abundance of male Burrowing Owl territories, Imperial Valley, California 2007.

CONCLUSIONS AND RECOMMENDATIONS

The model representing the best correlates of male Burrowing Owl territory abundance in the HCP Study Area contained the number of available burrows and the proportion of alfalfa in grid cells three years prior to the owl survey. The competing model in our initial analysis contained alfalfa four years prior to the survey, and the four models containing only alfalfa and burrows had the best AIC rankings of all the models tested. This was not surprising given that the type of vegetation surrounding Burrowing Owl nest burrows has been suggested by others to be a possible predictor of owl abundance (Rich 1986, Green and Anthony 1989, Haug and Oliphant 1990, Plumpton and Lutz 1993). Of the 9 crop types found to be used by a small sample of radio-tagged Burrowing Owls in the Imperial Valley (Rosenberg and Haley 2004), owls selected for barren ground near (<1,980 ft) and hay far (>1,980 ft) from nests. Our results provide evidence of the importance of alfalfa as a correlate of owl abundance in the HCP Study Area.

Although the addition of a spatial covariance term improved the fit of our best model, this model explained only 51% of the variability in local owl abundance across the HCP Study Area. This may be due to a variety of factors, including the resolution of the standardized grid cells, temporal variation in the correlates themselves (e.g., crops were rotated during our owl surveys), accuracy of the remote sensing analyses that we used to derive the crop estimates, and quality of the other correlates we used. For example, the IID's maintenance data were only available for each canal or drain as a whole, with no specific location. Because some of these structures were very long and maintenance activities are often locally concentrated (Ty Mull, pers. comm.), the spatial resolution of the data was not fine enough to determine with high accuracy the amount of maintenance each grid cell received. The categorization of maintenance activities also necessitated that we pool among categories because specific activities were often referred to in the database under more general terms. Because recent information suggested that maintenance activities can directly influence Burrowing Owl survival and dispersal (e.g., Catlin and Rosenberg 2006), we suspect our generalization of that data may have diluted its accuracy, which in turn reduced our ability to adequately assess the relative importance of the IID's maintenance as a correlate of abundance. Based on our initial objective to identify the best correlates of owl abundance for use in stratifying the HCP Study Area prior to future population surveys, further investigations into correlations between specific IID maintenance activities and owl abundance may prove beneficial.

The best model identified the variables that were most correlated to owl abundance, which is a widely accepted method of choosing variables that can be used to construct strata for stratified random sampling (Cochran 1977:128). Because it did not explain all of the variation in owl abundance and its correlative power may not be stable over time (e.g., farming practices change or local owl abundances become limited by other factors), the efficacy of using this model for constructing strata needs to be tested. A validation of this correlative model with an independent dataset is essential because if the correlation between these variables and owl abundance does not remain constant or increase over time, then the stratification will become inefficient and the precision of the resulting population estimates will be reduced (Cochran 1977:100-102). In light of these concerns, chapter 17 provides a comparison of this model against alternatives to stratifying the HCP Study Area, and a recommended alternative is provided.

Chapter 13

POTENTIAL CORRELATES OF AREA OCCUPANCY BY MALE BURROWING OWLS

JEFFREY A. MANNING AND CAREN S. GOLDBERG

ABSTRACT. The Burrowing Owl population surveys described in previous chapters could provide information on rates of occupancy in local grid cells, which could provide valuable information for conservation and management and elimination of areas from future surveys. In this chapter, we focused on identifying potential correlates of area occupancy by male Burrowing Owls. We used the information theoretic approach to compare the fit of various logistic occupancy models to the data, where each model structure included a different potential correlate and/or assumed variable or constant detection probabilities. We found that >95% of the 3x3 grid cells in the HCP Study Area were occupied, and that none of the models fit the data well, preventing us from identifying a correlate of occupancy.

INTRODUCTION

In our detailed study plan, dated 18 January 2007, we proposed to use the Burrowing Owl survey data and datasets of potential correlative factors collected for Tasks 1 and 4 under Objective 1 to estimate the probability that sampling units (grid cells) were occupied by ≥1 owl territories. This information was intended to supplement the distribution of owl point locations obtained from conducting the complete census under Objective 1 of the study plan. It was also to provide a GIS polygon layer of independent sampling units with probabilities of occupancy categorized according to either low and high probabilities of occupancy. This GIS layer could also be viewed as a probabilistic distribution map, and was anticipated to be generated each year, based on the correlative factor(s) determined to be the most strongly correlated to probabilities of occupancy. Here, we present the findings from this approach.

METHODS

For this study, we used the original territory locations derived from the 3 point-coordinate capture-recapture survey occasions determined from the 2007 census of 3x3 km grid cells in the HCP Study Area. We used these data to construct a multinomial occupancy encounter history for each grid cell, where a given grid cell was considered occupied (1) on a given survey occasion if ≥1 owl territories were detected and unoccupied (0) if no territories were detected. We applied these binomial decisions for each survey occasion.

We fit occupancy models to the occupancy encounter history using Program PRESENCE 2.2 (Hines 2006), with the goal of determining the corrected estimate of the proportion of 3x3 km grid cells occupied in the HCP Study Area. We applied an information theoretic framework to testing multiple working hypotheses (Burnham and Anderson 2002), developed a set of 28 *a priori* hypotheses, and constructed an occupancy model for each

hypothesis. Our base model [ψ (.) p(.)] represented the hypothesis that the proportion of occupied grid cells (ψ) did not vary according to an environmental covariate and the probability of detecting occupancy (p) was constant among occasions. We further constructed models that differed in the environmental variable (soils, fallow land, alfalfa, maintenance activities, water conveyance structure length and type, burrows, and crop richness) hypothesized to be a potential correlate of occupancy of grid cells. We constructed simple linear models, and included only single covariates that we suspected may be important or previously reported in the literature to be important for Burrowing Owls. Because our sampling methodology involved surveying different portions of the HCP Study Area at different times over the 30 days (e.g., we would conduct 4 consecutive occasions in one portion before conducting 4 occasions in another portion, and we divided the area into 6 separate portions), we pooled the data across the different portions to create our 4-occasion encounter histories. To avoid problems with the possible confounding of time and portion of the HCP Study Area surveyed, we assumed that detection was constant in our models. We used Akaike's Information Criterion (Akaike 1973) to determine the most parsimonious model and considered it to be our best model. We assessed the fit of our global model to the occupancy encounter history data using 1,000 bootstraps for Mackenzie and Bailey's Goodness-of-fit test (Mackenzie and Bailey 2004).

RESULTS

We observed ≥1 male Burrowing Owl territories during ≥1 survey occasions in 261 (95%) of the 274 grid cells in the HCP Study Area during the 2007 surveys. We did not detect territories in the remaining 5% (13) of the grid cells, making the naïve (empirical) estimate of $\psi = 0.95$, which differs from the modeled estimate of ψ and can be interpreted as the probability that any grid in the HCP Study Area is occupied. The model with the smallest ΔAIC hypothesized that occupancy was a function of the dominant type of soil in grid cells, and there were no competing models (the next best model had a ΔAIC = 181). This model estimated a very high detection probability (p) of 0.97 (SE = 0.18).

Our best model (equivalent to a global model in its number of parameters) fit the data poorly (Goodness-of-fit $X^2 = 57.2$, $P = 0.001$), predicting an unconditional ψ that was equal to the naïve estimate (0.95, SE = 0.01) in the 13 grid cells where we did not observe territories. When conditioned on the encounter histories, this model predicted no occupancies that we did not detect.

Given the poor performance of this model and the absence of competing models, we also examined the fit and ability to correctly predict occupancy from various models with covariates that we constructed and found similar problems, with none passing the Goodness-of-fit test. Although there was little support for our base model containing no covariates (ΔAIC = 1058.94), its estimated p was also high (0.97, SE = 0.005), and it also predicted the proportion of occupied sites equal to the naïve estimate (ψ = 0.95, SE = 0.01).

CONCLUSIONS AND RECOMMENDATIONS

Given the high probability of detecting the presence of male Burrowing Owl territories in grid cells, and the high rate of occupancy, most of 274 grid cells in the sampling grid were occupied. The discrepancy between the 18 grid cells found in chapter 10 to contain zero territory centroids and the lower number (13) found here to be unoccupied was due to our use of owl locations in estimating occupancy. Because of the 2-dimensional nature of owl territories, locations of owls that occupy territories straddling grid cell boundaries can occur in ≥2 grid cells, and this edge effect led to classifying 5 of the grid cells without territory centroids as occupied during these analyses.

The failure of our global model to fit the data may stem from a variety of sources, including: 1) that the size of our grid cells, coupled with high detection probabilities, ensured a high rate of observed occupancy, particularly given the density of the owl population in 2007, 2) the owl population was saturated (but see Chapter 19), 3) our set of hypotheses were not comprehensive enough which could have incidentally led us to not measure the biologically correct correlative variable(s), 4) or our model structures may not have adequately accounted for additive or multiplicative biological processes that influenced occupancy. A reduced owl population or smaller grid cells would produce more variability among grid cells and may have yielded a different result, but our objective was to use the existing standardized grid intended for drawing random samples from prior to subsequent surveys.

The prediction of high occupancy rates (0.95) by the best model in grid cells where territories were not detected was likely due to the high rate of occupancy that essentially produced a homogeneous sampling grid of occupied cells. This extremely low number of unoccupied grid cells, compared to the large number of occupied cells, provided an extremely imbalanced dataset from which to estimate occupancy rates with our models, and explains the source of the poor fit. Furthermore, this may also explain why dominant soil type was the best correlate. Dominant soils were classified into only 3 types, and suitable soils was the dominant soil type in grid cells across the HCP Study Area (Figure 7.1E), including all of the grid cells where we did not detect owls, producing a nearly homogeneous distribution similar to that of occupancy rates. Thus, the response and correlate variables lacked adequate variability necessary to model a range of occupancy rates, and unoccupied grid cells were assigned the global (naïve) probability of occupancy.

Chapter 14

ELIMINATION OF AREAS DURING FUTURE SURVEYS DUE TO THE UNLIKELIHOOD OF BEING OCCUPIED BY MALE BURROWING OWL TERRITORIES

JEFFREY A. MANNING

ABSTRACT. Balancing cost and logistical effort is always a priority in developing long-term wildlife population monitoring programs. Here, I provide a brief discussion on how to prioritize survey efforts towards grid cells in the HCP Study Area with high probabilities of being occupied to reduce costs. During the establishment of the standardized sampling grid, several grid cells were removed because they lacked any above-ground IID water conveyance structures. There removal was necessitated by our conducting surveys only along water conveyance structures. Due to the high rate of occupancy among the remaining grid cells, dynamic changes in numbers of owls that can occur, and the robust ability of the sampling methodology developed in the following chapter to account for cells that are unoccupied during a given survey, no other cells were removed.

INTRODUCTION

I originally proposed to use the 2007 census data to determine if any and which grid cells in the HCP Study Area should be eliminated from the sampling grid (see detailed study design, dated 8 January 2007). I proposed to make such a determination on a cell by cell basis using the estimated local abundance from Chapter 10 and occupancy rates from Chapter 13. The approach involved eliminating grid cells where estimated abundance and occupancy rates were simultaneously low. This was intended to prioritize survey efforts towards areas with high probabilities of being occupied and coincidently improve the accuracy of population estimates.

As part of the development of the standardized sampling grid of 3x3 km cells in Chapter 9, several grid cells were removed because they lacked any IID water conveyance structures. The remaining grid cells contained a range of abundance estimates from 0 to 57 male Burrowing Owl territories, as reported in Chapter 10. The discrepancy between the 18 grid cells we reported in Chapter 10 to contain zero territory centroids and the 13 reported to be unoccupied during our occupancy modeling in chapter 13 was due to our use of owl locations in estimating occupancy rather than centroids. Because of the 2-dimensional nature of owl territories, the locations of owls along grid cell boundaries can occur in multiple grid cells, and this edge effect can lead to classifying cells without territory centroids as occupied. Nonetheless, as was shown in chapter 13, occupancy rates were consistently high across the HCP Study Area. The absence of variability in occupancy rates compromised the originally proposed effort to use them for making decisions on the selective elimination of cells from the sampling grid.

Several of the 18 grid cells where we did not detect territory centroids in 2007 were dominated by urban developments, but they did contain above-ground water conveyance structures maintained by the IID. Such structures near other urban areas in the HCP Study Area did support territories during this study period. For these reasons, grid cells dominated by urban development that contain above-ground water conveyance structures may still contain suitable nesting habitat and could be occupied in future years. In light of the dynamic changes in the numbers and distribution of territories during the breeding season (see Chapter 19), it would not be prudent to permanently remove these grid cells from future surveys. Furthermore, because the stratified random sampling methodology presented in the following chapter is reliant on low, medium, and high owl abundances among grid cells, the few grid cells where we surveyed and did not detect occupancy in 2007 can be appropriately included into the low abundance stratum, thereby making them available for random selection in future surveys. When these grid cells are randomly selected, the resulting abundance estimates at that time can be used to appropriately calculate the overall estimate and sampling error for the low abundance stratum.

Chapter 15

DEVELOPMENT OF A STRATIFIED RANDOM SAMPLING METHODOLOGY TO SURVEY FOR AND ESTIMATE MALE BURROWING OWL TERRITORY ABUNDANCE

JEFFREY A. MANNING AND CAREN S. GOLDBERG

ABSTRACT. As with any long-term population monitoring program, a standardized sampling design that minimizes the required sample size, optimizes the allocation of survey effort, and reduces costs while maintaining high levels accuracy at all stages of the survey is needed for surveying Burrowing Owls in the HCP Study Area. Here, we present a stratified random sampling methodology for estimating the abundance of male Burrowing Owl territories. The method involved identifying a range of minimum required sample of grid cells needed to achieve estimates with specified levels of precision. It also determined the optimal allocation of grid cells to the corresponding strata by accounting for differential variances in owl abundance and costs associated with surveying each strata (i.e., based on our standardized sampling protocols, more owls equated to more stops that required more time and higher costs). We demonstrated how this sampling methodology greatly improved precision, and recommended its use.

INTRODUCTION

Prior to initiating a long-term population monitoring program for Burrowing Owls in the HCP Study Area, a standardized sampling design that minimizes the required sample size, optimizes the allocation of survey effort, and reduces costs while maintaining high levels accuracy at all stages of the survey is needed. Wildlife monitoring programs such as these generally involve choosing a desired level of detectable change in the population. Many decisions made in the early planning stages influence the power and cost of conducting surveys intended to detect that desired level. A well designed sampling approach can reduce costs while maintaining the ability to detect the desired level of population change. As described in the general introduction, reducing measurement and sampling errors can increase the accuracy of total population estimates. Reducing these errors essentially increases statistical power, and sampling design is an important mechanism by which to accomplish this objective. Statistical power can be increased by (1) establishing homogeneous strata, (2) measuring concomitant information, and (3) selecting an efficient sampling design (Kuehl 1994).

With the proper sampling design, empirical estimates of population size can be used to compute finite rates of annual population growth (λ) with a level of precision needed to achieve a desired level of detecting a change in the Burrowing Owl population. Because the HCP specified that "the appropriate significance level for ... [λ] will be determined by a statistician," a range of sample sizes that would be required to achieve a desired level of precision surrounding population estimates (or distance from the true population

mean) would be advantageous prior to making such a determination. The desired precision is important because it is a function of sample size (or visa versa) which corresponds to the level of survey effort and cost. Larger sample sizes (e.g., more grid cells surveyed) are more precise, which increase the ability to detect a smaller change in the population between years than from smaller samples, but at a greater financial cost. Because management actions involve a balance between cost and reliability of biological data, determining how many grid cells would be required to attain a particular level of precision (and detectable level of population change), is a practical and efficient method to establish the annual level of survey effort in the HCP Study Area. This method of computing a population growth rate would also enable the IT to immediately assess the stability of the Burrowing Owl population and determine if adjustments to the Burrowing Owl Conservation Strategy are needed prior to the onset or completion of the demographic study referenced in section 4.5.3 of the HCP.

Time and money limitations typically constrain population surveys to a sample of areas that represent a fraction of the area occupied by the population of interest. Here, each area is represented by a 3x3 km grid cell, and sampling error refers to the variability in abundance of male Burrowing Owl territories among these sampling units. In these situations, a carefully selected sampling design can reduce sampling error and improve statistical power (Kuehl 1994). Designs such as cluster sampling, randomized block, and stratified random sampling reduce sampling error by categorizing sampling units according to their similarity or dissimilarity and estimating abundance in each class separately.

Because abundance of owls was shown to be unevenly distributed across the HCP Study Area (see Chapter 10), a simple random sample of areas would likely lead to imprecise estimates of the total size of the population (Caughley 1977:27, Williams et al. 2002:247). An accurate estimate of population size can be obtained with sampling designs that account for the size, shape, number, and placement of sampling units across areas where abundance is unevenly distributed (Caughley 1977:27, Williams et al. 2002:247).

A commonly used design to estimate the size of wildlife populations in large areas where abundance is unevenly distributed is stratified random sampling (Caughley 1977:27, Cochran 1977:87, Williams et al. 2002:249). The area supporting the total population of interest is subdivided into areal sampling units, and these are categorized according to their similarity in animal abundance (e.g., low, medium, and high). These categories are referred to as strata, and a random sample of units is drawn separately from each stratum. Animals are counted in the randomly sampled units and the strata abundances are summed to estimate a total population size. This stratification of units into similar abundances reduces sampling error among strata and the estimated total population estimate (Cochran 1977:88). As with the other designs mentioned above, this sampling design assumes that population counts in sample units are without measurement error. Because measurement error probably cannot be completely eliminated (Steenhof and Kochert 1982, Fraser et al. 1983) and is not accounted for in these methods, it is very important to reduce measurement error when using one of these designs.

In this chapter, we present the results from a stratified random sampling design we developed for sampling and estimating the total population size of male Burrowing Owl territories in the HCP Study Area. As part of this effort, we calculated a range of sample sizes that would be required to achieve a desired level of statistical precision surrounding

population estimates (or distance from the true population mean), from which a determination of the desired level of change can be based. We accomplished this with the local abundance estimates from 2007, and the design relies on survey methods that minimize measurement errors, such as the point-coordinate capture-recapture survey technique presented in Chapter 5 and used in producing the local abundance estimates.

METHODS

Minimum Required Sample Size

We determined the size of random samples of grid cells that would be required to be surveyed in the HCP Study Area to achieve an estimated population mean at specified levels of precision (or distance away from the true population mean; Williams et al. 2002:64). Here, the population refers to the 274 grid cells from which a random sample would be drawn from and surveyed each year, and the mean refers to the mean owl abundance in grid cells. We based this analysis on sampling without replacement (e.g., a grid cell would be surveyed once per population survey), with an adjustment for the influence of the finite population of 274 grid cells available for sampling, using the following equations:

$$n = \left(\frac{z_{\alpha/2}}{d} CV \right)^2 \qquad \text{Equation 15.1}$$

where n is the sample size needed, α is the level of statistical significance, $z_{\alpha/2}$ is the upper $\alpha/2$ point of the standard normal distribution, d is the specified distance in multiples of the population mean, and CV is the population coefficient of variation, which we calculated from the estimated abundance in each 3x3 km grid cell. The finite population adjusted n was then computed with

$$n' = n/(1 + n/N) \qquad \text{Equation 15.2}$$

where N is the total population of grid cells (274) available for sampling.

This approach is commonly used in wildlife science to determine a minimum required sample size, and negates the bootstrapping that we originally proposed.

Stratum Boundaries

Stratification of a study area into relatively homogeneous subunits can improve the precision of population estimates (Cochran 1977). Stratification increases efficiency in sampling effort and is commonly used to improve the precision of wildlife population estimates. We determined the numerical boundaries of 3 strata (low, moderate, and high owl abundances) using the cumulative of the square-root of the frequency method, which should provide an efficient stratification (Cochran 1977:127-132). For this analysis, we used frequencies of owl abundance in increments of 5. We then used these numerical

stratum boundaries to post-stratify each grid cell across the HCP Study Area by the estimates of Burrowing Owl abundance in 2007. Using this same method, stratum boundaries can be recalculated prior to each subsequent survey using owl abundance or a correlate of it, and should yield relatively precise estimates.

Optimal Allocation of Survey Effort among Strata

Optimal allocation of the minimum required sample size among the predefined strata improves precision and survey efficiency. We determined the optimal allocation of effort among strata by taking into account stratum variances, sampling costs, and stratum size (Williams et al. 2002:65-67). Sampling costs were based on cost constraints in each stratum according to the mean length of survey route and mean number of owls per grid cell in a stratum. This approach allocated samples to each stratum in a manner that minimized stratum variances given an overall cost constraint C that equaled $C_1 n_1 + ... + C_i n_i$ for $n = n_1 + ... + n_i$ available samples of grid cells. This constrained optimization had an optimum solution of

$$n_i = n\left(\frac{(N_i \times \sigma_i)/\sqrt{C_i}}{\sum_{i=1}^{I}(N_i \times \sigma_i)/\sqrt{C_i}}\right) \quad \text{Equation 15.3}$$

where N_i is the total number of grid cells, σ_i is the standard deviation, and C_i is the cost constraint [($\bar{x}$ km of survey route × 0.19 minutes/km) + ($\bar{x}$ number of owls × 2 minute stop/owl)] associated with stratum *i*.

Precision of Burrowing Owl Territory Abundance Estimates by Stratified Random Sampling

When applied appropriately, stratified random sampling nearly always results in greatly improved precision of estimated means or totals than that obtained from a comparable simple random sample (Cochran 1977:98). To demonstrate how well stratified random sampling improved the precision of our estimates over simple random sampling with the same level of survey effort, we repeatedly sampled the estimates of abundance in the 274 grid cells from the entire 2007 dataset, thereby developing a series of simulated sample datasets from the original data. For each sampling method, we conducted 1,000 simulations by subsampling the grid cells, without replacement. For these simulations, we chose to use the minimum required sample size to be within 10% of the true population size that was approximated in Chapter 10 by summing the local abundance estimates from the 2007 census. For stratified random sampling simulations we also applied optimal allocation of effort among the 3 strata determined above.

Unbiased simple random sampling estimates of population size ($\hat{X}_{SR}$) for the HCP Study Area were calculated by multiplying the total number of grid cells by the ordinary sample mean ($\bar{x}_{SR}$) in the HCP Study Area:

$$\hat{X}_{SR} = N \times \bar{x}_{SR} = N \times \sum_{j=1}^{n} \hat{x}_j / n_j \qquad \text{Equation 15.4}$$

where $\hat{x}$ is the abundance estimate associated with the *j*th randomly selected grid cell *n*.

We calculated the variance of each simple random sampling estimate ($\hat{\sigma}^2_{\hat{X}_{SR}}$) with a finite population adjustment:

$$\hat{\sigma}^2_{\hat{X}_{SR}} = N^2 \times \frac{s^2}{n}(1 - n/N) \qquad \text{Equation 15.5}$$

where s^2 is the usual sample variance. We then used this variance to calculate 95% confidence intervals.

Following Steel et al. (1997:595-597), we calculated unbiased stratified random sampling estimates of population size ($\hat{X}_{ST}$) as:

$$\hat{X}_{ST} = \sum_{i=1}^{n} N_i \times \bar{x}_i \qquad \text{Equation 15.6}$$

where N_i is the total number of grid cells in the *i*th stratum and $\bar{x}_i$ is the mean abundance estimate associated with the *i*th stratum.

The variance of the estimated population mean from a stratified random sample was calculated as:

$$\hat{\sigma}^2_{\bar{x}_{ST}} = \frac{1}{N^2} \sum_{i=1}^{3} N_i (N_i - n_i) \times \frac{s_i^2}{n_i} \qquad \text{Equation 15.7}$$

We used this variance to calculate 95% confidence intervals surrounding the mean of each simulated stratified random sample and multiplied the upper and lower bounds by *N* to obtain the intervals surrounding each population estimate.

To compare between the two sampling methods, we calculated the 95% confidence interval width (CI) for each bootstrapped population estimate, computed the mean of those confidence interval widths ($\overline{CI}$) separately for each sampling approach, and

assessed the difference in this measure of precision. All analyses were performed in R (Ihaka and Gentleman 1996).

RESULTS

We present a range of minimum required numbers of 3x3 km grid cells to be randomly sampled and surveyed to achieve specified levels of precision (Table 15.1). A minimum of 119 grid cells (43% of the HCP Study Area) would need to be surveyed using a simple random sampling approach to ensure that the population estimate is within 10% of the true population size, and 44 grid cells would be required for 20% (Table 15.1; Figure 15.1). These levels of precision also specify the minimum detectable level of annual population change under simple random sampling by multiplying them by 2; but, stratification and optimal allocation of effort can further improve these levels of precision and narrow the statistically detectable level of population change.

Our analysis of numerical boundaries for the 3 strata we selected determined the following ranges in abundance: 0 - 14.9 in the low abundance stratum, 15.0 - 29.9 in the moderate, and 30 - 54.9 in the high (Table 15.2; Figure 15.2). Based on these stratum boundaries, there were 123 grid cells in the low abundance stratum, 95 in the moderate, and 56 in the high.

The optimal allocation of effort among the 3 strata was 50.4% of the low, 32.6% of the moderate, and 48.2% of the high abundance strata (Table 15.3).

For our assessment with the simulated samples bootstrapped from the census of all grid cells, we used the minimum required sample size required to be within 10% of the true population size (119 grid cells; Table 15.1). For this selected sample size, the optimal allocation was determined to be 62 grid cells in low abundance stratum, 31 in the moderate, and 27 in the high. Based on these simulations, the precision of estimated Burrowing Owl territory abundance was improved by stratified random sampling [$\overline{CI}$ = 352.7 male owl territories (95% CI: 351.8 - 353.7)] compared to simple random sampling [($\overline{CI}$ = 977.6 (95% CI: 975.0 - 980.2)]. The $\overline{CI}$ obtained from simple random sampling represented almost 20% of the true total population size of 4,879 estimated in chapter 10 (or 10% on either side of the estimate), whereas that from stratified random sampling was 7% of the true total population size.

CONCLUSIONS AND RECOMMENDATIONS

The minimum required sample of grid cells to achieve specified levels of precision and rates of change in population size we present here were based on the survey protocols and analytical methods presented in Chapters 5, 7, and 10. Our results provide basic information needed to choose a desired level of detectable change in the population by considering the statistical precision of the population estimates. Once a minimum level of change is chosen, the minimum required sample size can be determined from Table 15.1. The smallest rate of change that can be detected with 95% certainty from simple random sampling is approximately 20% (2 x 10% of the distance each sample estimate

would be from its true population size) by sampling 43% of the HCP Study Area. As an example of such a change, a 20% decline would reflect the loss of 999 of the 4,998 male territories detected in 2007. However, stratified random sampling can improve this level of precision and narrow the level of detectable rate of change.

To apply the stratified random sampling methodology, the optimal level of effort in each stratum would need to be determined for the minimum required sample size chosen. Once an optimal level of effort was determined, optimal allocation would be recalculated following the re-stratification of the sampling grid prior to each population survey. Based on our assessment with our simulated samples, that same sample size (119; but, stratified, optimally allocated, and surveyed following our methods) should provide estimates of population size that lie $\leq 3.5\%$ from the total population size that would have been estimated if all grid cells in the HCP Study Area were surveyed. This represents a 186% gain in precision over an equal level of simple random sampling.

In theory, a stratified random sample of 119 grid cells would enable the IT to detect a $\geq 7\%$ change in λ with 95% statistical confidence. However, our stratified random sampling methodology assumed no measurement error during surveys in our grid cells, although we believe our standardized survey protocols and number of point-coordinate capture-recapture occasions minimized it to a negligible level (Steenhof and Kochert 1982, Fraser et al. 1983). Furthermore, this sampling methodology was based on the construction of strata from the empirical frequency of owl abundance, which was the ideal variable for stratification (Cochran 1977:100). Although this currently was the best biological information available to construct strata, its application in subsequent surveys would assume that local owl abundances would change little. The next best alternative to using owl abundance would be to use a variable that is closely correlated to it (Cochran 1977:128), which is why we developed the correlative model in Chapter 12. That model determined the group of variables that were most correlated with abundance of owls in 2007, and in Chapter 17, we compare its use to stratify the HCP Study Area prior to an independent survey to other possible methods of stratification. Because that correlative model did not explain all of the variation in owl abundance and its correlative power may not be stable over time (e.g., farming practices change or local owl abundances become influenced by other factors), we expect that the precision presented here may be higher than realized in subsequent surveys (Cochran 1977:100-102). Thus, it is important to consider the results in Chapters 17 and 18 before selecting the final method to stratify the HCP Study Area prior to each subsequent survey and choosing the minimum required sample size for a specified level of detectable rate of change.

Table 15.1. Size of a simple random sample (no. of grid cells) required to ensure a population size within a specified distance from the true number of owls.

Distance from true mean (%)	Finite adjusted sample size
0	274
10	119
20	44
30	22
40	13
50	8
60	6
70	4
80	3
90	3

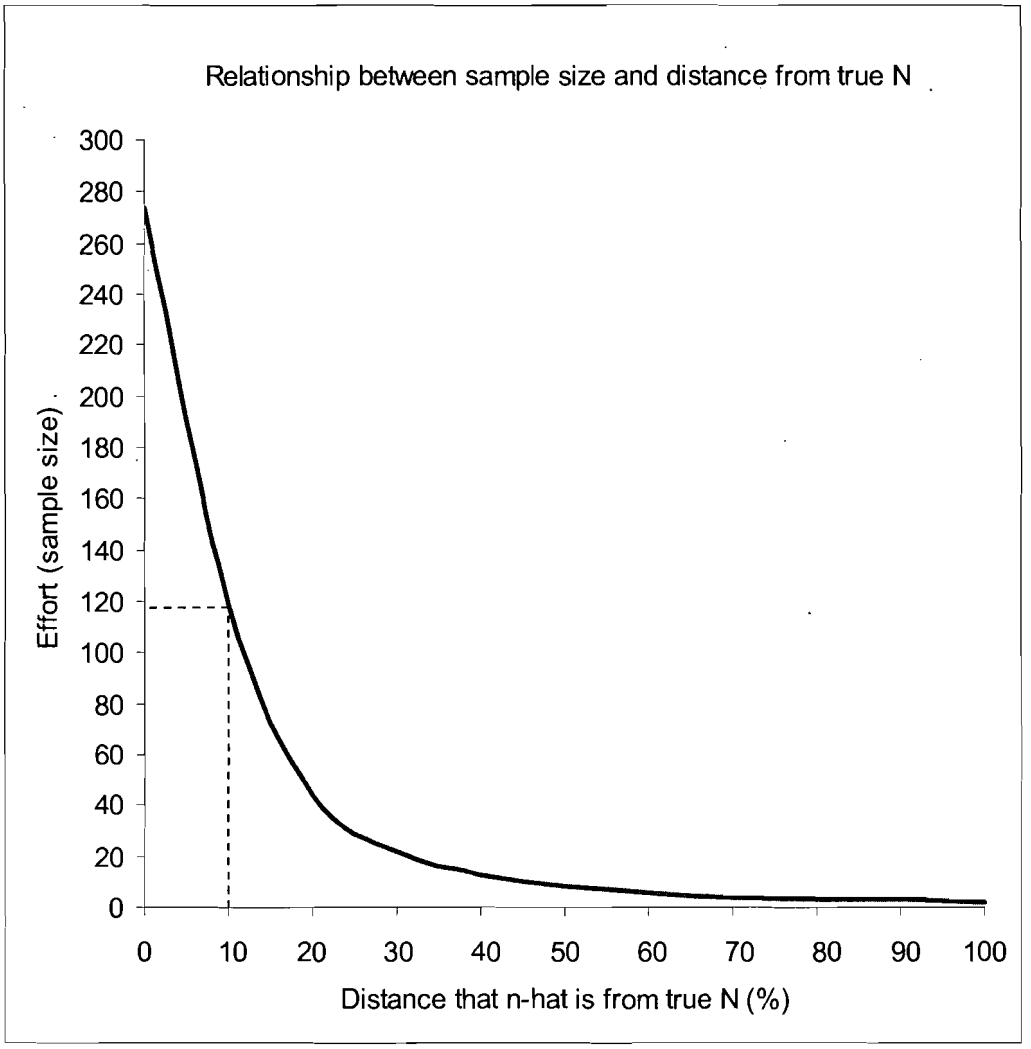


Figure 15.1. Graphical representation of Table 15.1: size of a simple random sample (no. of grid cells) required to ensure a population size within a specified distance from the true number of owls and minimum detectable population change. Dotted lines demarcate the level of simple random sampling effort (number of 3x3 km grid cells) required to detect a minimum change of 20%, which can be improved through stratification and optimal allocation.

Table 15.2. Determination of sampling strata boundaries of Burrowing Owl abundance during the prehatch stage of the breeding cycle using the cumulative square root method (Cochran 1977:127-131), Imperial Valley, California, 2007. These strata were developed as part of a long-term stratified random sampling survey method.

Abundance range	No. of cells $f(y)$	$\sum\sqrt{f(y)}$	Strata	Range	Cells (N)
0-4.99	52	7.21			
5-9.99	34	13.04			
10-14.99	37	19.12	1 (low)	0-14.99	123
15-19.99	37	25.21			
20-24.99	39	31.45			
25-29.99	19	35.81	2 (moderate)	15-29.99	95
30-34.99	23	40.61			
35-39.99	16	44.61			
40-44.99	7	47.25			
45-49.99	6	49.70			
50-54.99	4	51.70	3 (high)	30-54.99	56

Stratum Boundaries	
max $\sum\sqrt{f(y)}/3 =$	17.23
2xmax $\sum\sqrt{f(y)}/3 =$	34.47
3xmax $\sum\sqrt{f(y)}/3 =$	51.70

Table 15.3. Optimal allocation of survey effort among 3 strata of estimated local abundance for estimating the annual population size of male Burrowing Owl territories in the HCP Study Area, Imperial County, California, based on data from 2007. $\bar{x}$ indicates mean.

Strata	Number of owls ($\bar{x}$)	Average length of survey route ($\bar{x}$ km)	Cost constraint ($\bar{x}$ minutes)	Total cells	Optimal sample size of Total cells (%)
Low	6.03	12.24	76.46	123	50.4
Moderate	21.07	15.82	125.39	95	32.6
High	38.13	16.96	165.56	56	48.2

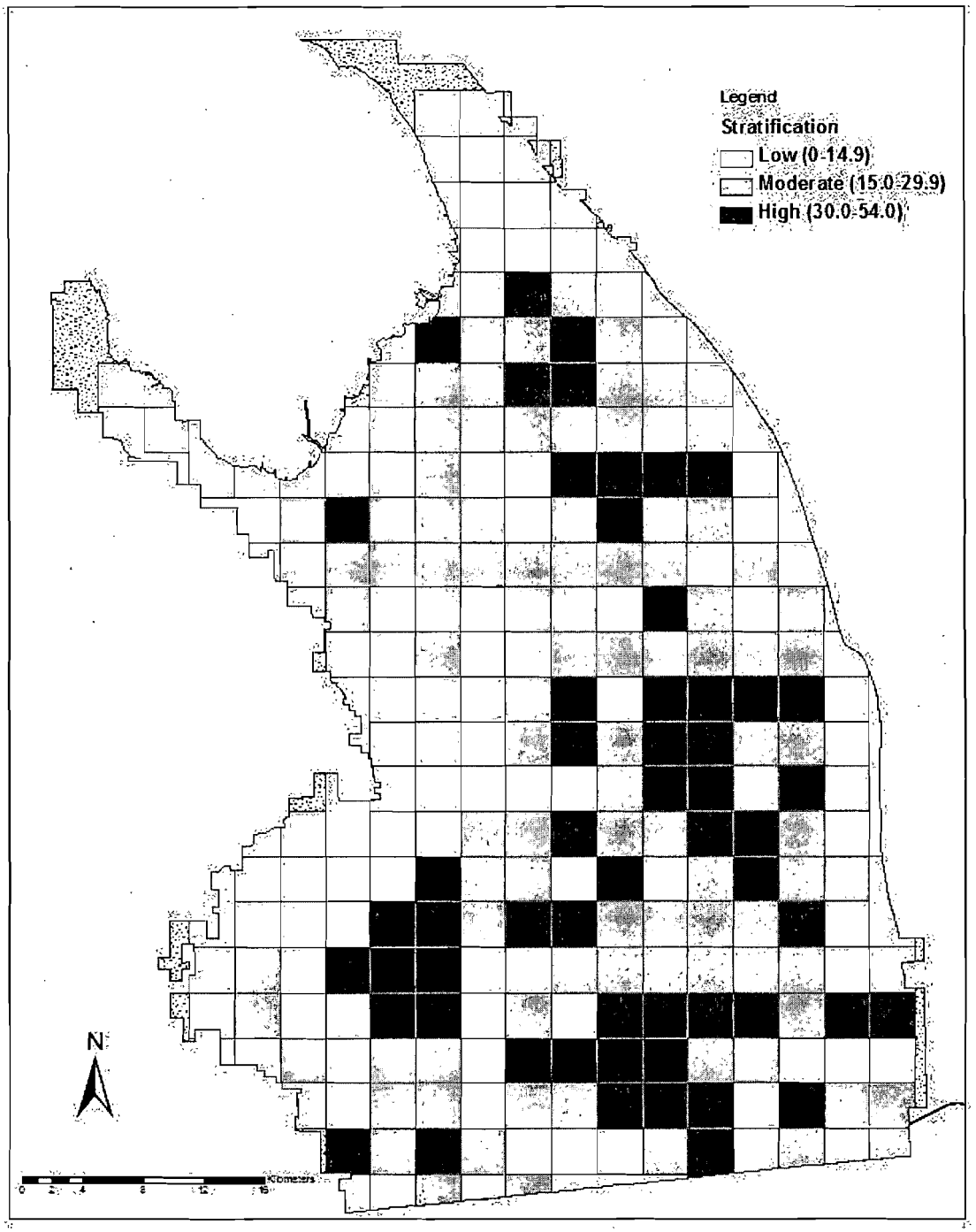


Figure 15.2. Post-stratification of Burrowing Owl abundance during the prehatch stage of the breeding cycle, Imperial Valley, California, 2007. These strata were developed as part of a long-term stratified random sampling survey method.

Chapter 16

MAXIMUM LIKELIHOOD ESTIMATES OF LOCAL MALE BURROWING OWL TERRITORY ABUNDANCE IN 2008

JEFFREY A. MANNING

ABSTRACT. Validation of models or statistical methods often includes testing those resulting tools with a dataset that is independent from the original data used to develop the tool. To validate the stratified random sampling strategy for Burrowing Owls in the HCP Study Area and the correlative model constructed for constructing sampling strata, an independent dataset was needed. I computed maximum likelihood estimates of local male Burrowing Owl territory abundance in 3x3 km grid cells from an independent dataset collected in 2008. These estimates were from point-coordinate capture-recapture survey occasions completed along the same IID rights-of-way surveyed in 2007, and following the same survey and analytical methods. By summing the grid cells, the approximated true population size in 2008 was 3,557 territories (95% CI: 3,218-3,895).

INTRODUCTION

To validate the sampling methodology developed in Chapter 15, an independent and comparable dataset was needed. In this chapter, I present the estimated local abundances calculated from a complete census of the IID's rights-of-way in the HCP Study Area in 2008.

METHODS

Between 28 March - 30 April, 2008, four point-coordinate capture-recapture survey occasions were completed along the same IID rights-of-way surveyed in 2007. Surveys and analytical methods followed those described in Chapters 5, 6, 7, and 10. The resulting male Burrowing Owl territory data from this census was used to compute local abundance estimates across the same standardized 3x3 km-resolution sampling grid applied to the 2007 census data. The sum of these grid cells was used to provide an approximated true population size in 2008.

RESULTS

Raw counts during single survey occasions ranged from 2.403-2.966 (Table 16.1), and the number of single detections without nests was similar to that found in 2007. Based on a sum of the population estimates in grid cells, a total of 3,557 (95% CI: 3,218-3,895) male Burrowing Owl territories was estimated to be present in the HCP Study Area during the prehatch stage of the breeding cycle in 2008. Local abundances within grid cells ranged from 0-55 territories, and the number of grid cells where no territories were detected increased to 21 (3 more) compared to 2007 (Figure 16.1).

Local abundances were lower on average than that found in 2007 (Figure 16.2), with 75% of the cells containing an estimated ≤20 territories (Figure 16.3). These low estimates of abundance coincide with counts in those cells and associated low standard errors that approximate zero (Figure 16.3), suggesting negligible measurement error or poor performance of the capture-recapture models fit to those cells.

CONCLUSIONS AND RECOMMENDATIONS

I estimated the population size in 2008 to be 3,557 (95% CI: 3,218-3,895) male Burrowing Owl territories. This estimate was derived by summing the local abundances, and can be used as the approximated true population size for comparing against sampled estimates in the following chapter.

This population size represented a marked decline compared to that estimated from the 2007 census. This coincided with slightly lower local abundances on average than that found in 2007 (see Chapter 10), and an increased number of apparently unoccupied grid cells.

Our survey protocols, level of survey effort, and analytical methods were standardized in both years, and all but one survey team in 2008 had at least 1 member from the survey teams used to complete surveys in 2007. Therefore, this difference was not due to differences in measurement error between the 2 years. Because a census was completed both years, this difference also cannot be attributed to sampling error. Furthermore, field biologists were asked to provide anecdotal reports on the presence of owls detected outside of the IID's rights-of-way in both years, and that information suggested that very few owls were outside of our survey areas during both years. Thus, this difference is largely due to a change in the total number of male Burrowing Owl territories present in the HCP Study Area.

The intended use of the 2008 census data was as an independent dataset for validating the survey methodology developed from the census data collected in 2007. That methodology was derived from a standardized grid of sampling units that were predominantly 3x3 km. This resolution was chosen, after communications with Dr. Bryan Manly, to balance the needs for an adequate number of territories in grid cells for capture-recapture modeling and a sufficient number of sampling units from which to draw random samples from each year. That decision was based from the best biological information available at that time, the census data from 2007. By using that empirical data with the intention of developing a standardized grid to be used for sampling in subsequent years, the sampling grid that was established assumed that the population data from 2007 was representative of that anticipated to be present in subsequent years. Thus, the unanticipated marked change in the total population size and local abundances between the 2007 and 2008 breeding seasons may compromise the validation of that methodology.

Table 16.1. Number of Burrowing Owl detections by survey occasion during the prehatch stage of the breeding cycle in the HCP Study Area, Imperial County, California, 2007. Owls detected once and without a nest were removed from the data.

	Survey Occasions		
Type of detection	1	2	3
Once without nest	123	233	203
All other detections	2,279	2,733	2,731
Mean/cell[1]	8.8	10.9	10.8
Standard deviation/cell[1]	7.5	8.9	9.1

[1] Calculated with total detections from all 274 3x3 km grid cells.

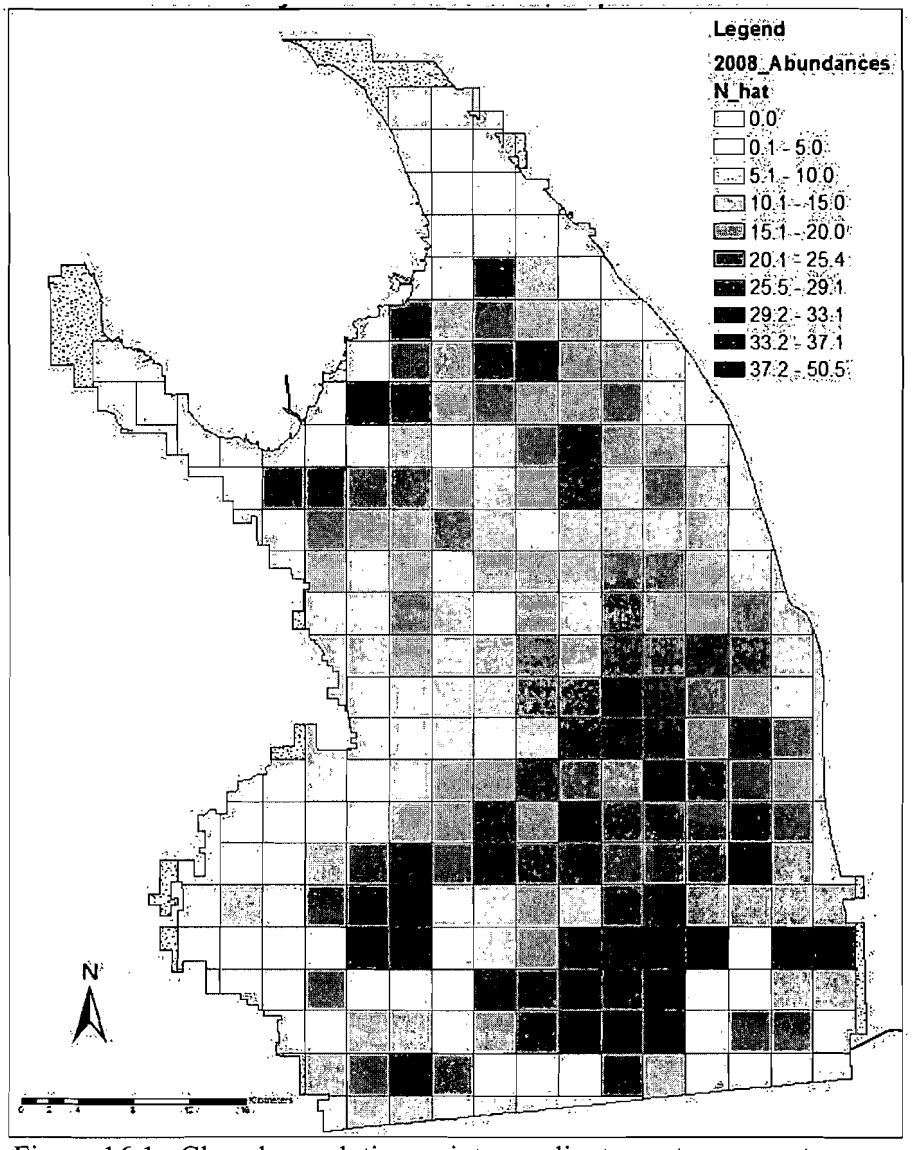


Figure 16.1. Closed-population point-coordinate capture-recapture estimates of local male Burrowing Owl territory abundance in 3x3 km grid cells in the IID's HPC area, Imperial County, California, April 2008. Stippled areas were not surveyed due to the absence of above-ground water conveyance structures.

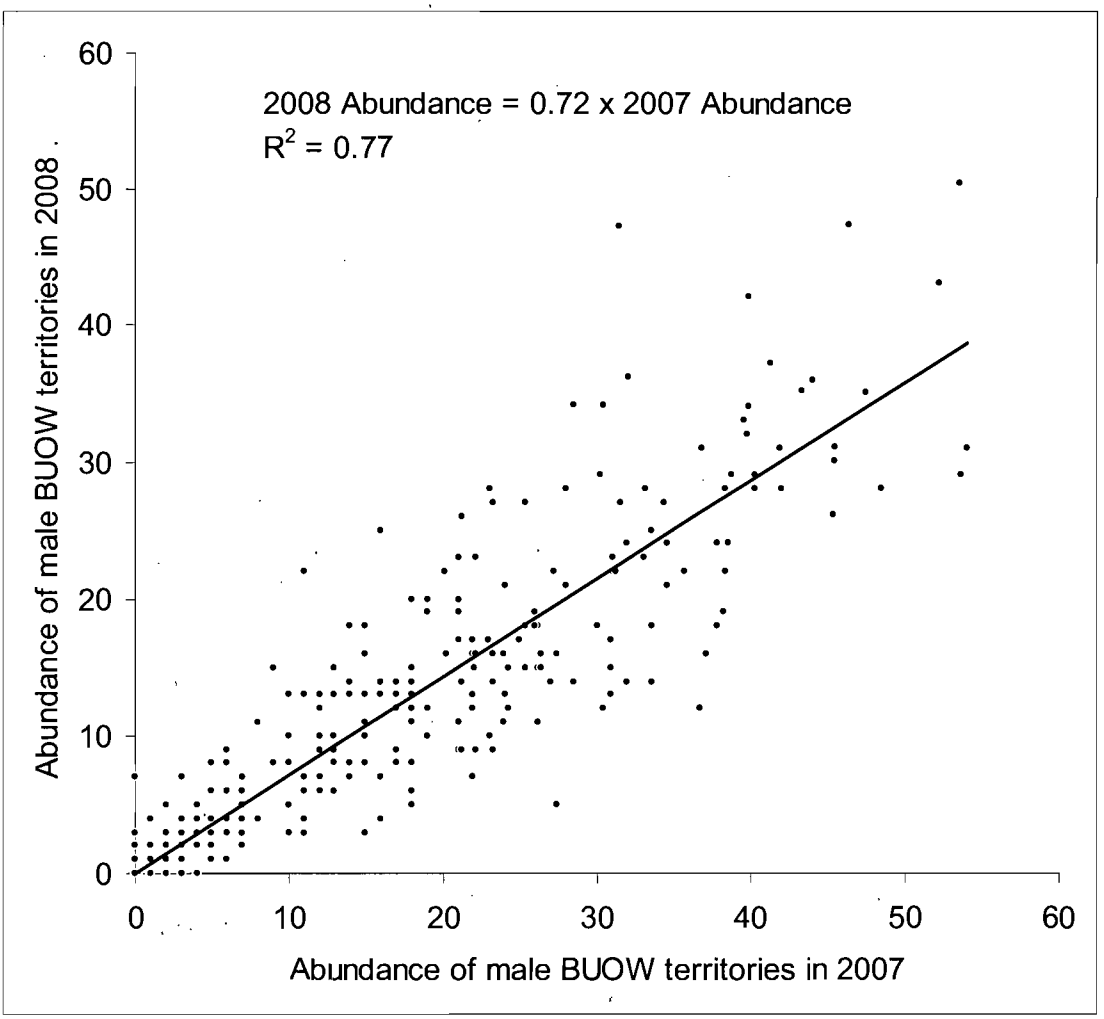


Figure 16.2. Linear relationship in the abundance of male Burrowing Owl territories in 3x3 km grid cells during the preatch period of the breeding cycle between 2007 and 2008 in the HCP Study Area, Imperial County, California.

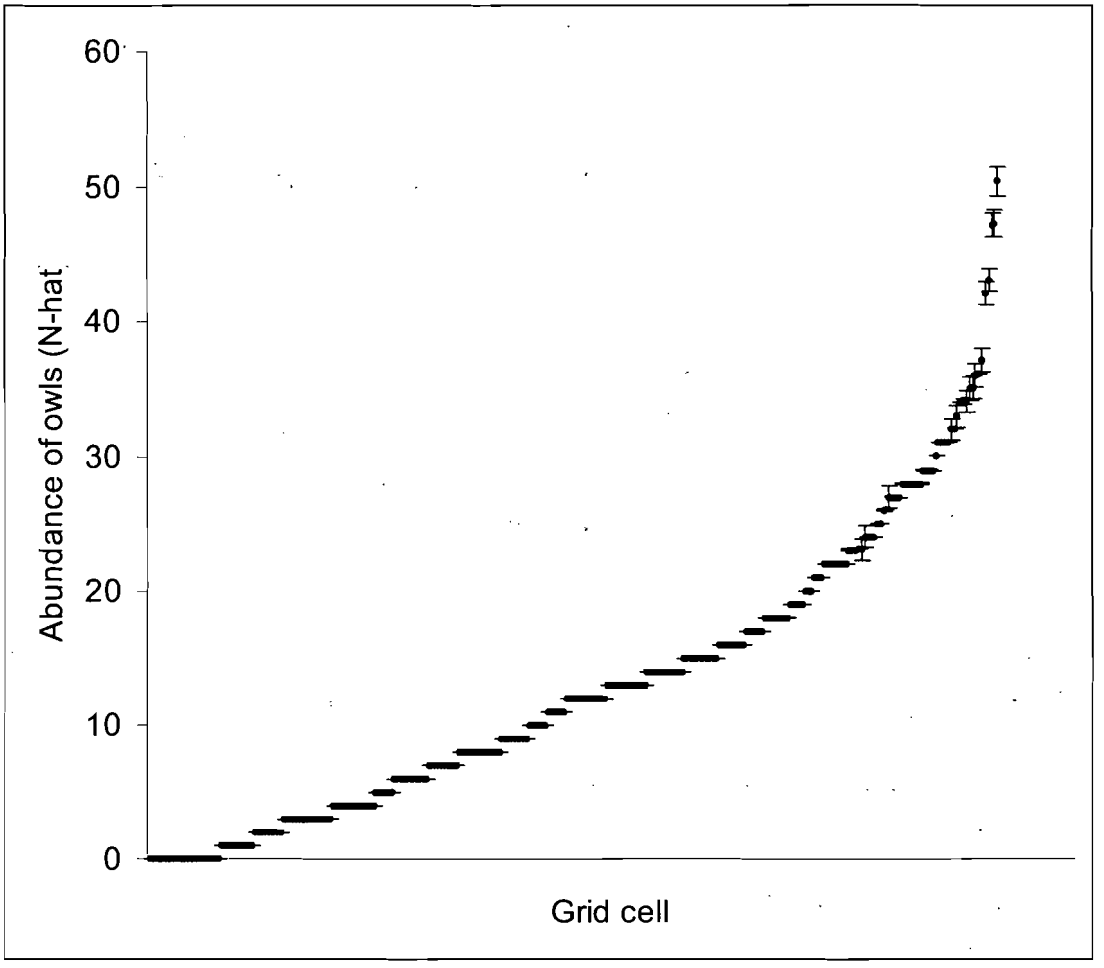


Figure 16.3. Estimates of local male Burrowing Owl territory abundances in 3x3 km grid cells in the HCP Study Area, Imperial County, California, 2008. Data are presented according to increased abundances. Vertical bars are standard errors.

Chapter 17

VALIDATION OF STRATIFIED RANDOM SAMPLING METHODOLOGY TO SURVEY FOR AND ESTIMATE MALE BURROWING OWL TERRITORY ABUNDANCE

JEFFREY A. MANNING AND CAREN S. GOLDBERG

ABSTRACT. Long-term population sampling methods should be validated to assess reliability in estimating population size. Here, we validate our stratified random sampling methodology and compare the performance of our correlative model (intended for constructing strata) against alternative methods of stratifying the HCP Study Area. Our sampling methodology was validated nicely with the independent population data in 2008. We found that the correlative model was not efficient at constructing strata. However, a census comprised of a single survey occasion prior to sampling, but during the same prehatch stage of the breeding cycle provided a relatively efficient method of stratifying and greatly improved the precision of the stratified random sampling methodology.

INTRODUCTION

A primary reason for sampling a population is to avoid the relatively high cost of conducting a complete census. We developed the optimally allocated stratified random sampling methodology in Chapter 15 using the frequency distribution of empirical abundance estimates from our census in 2007. Based on those empirical data, we also showed that our methodology can improve the precision of population estimates 186% from that which could be obtained from an equal effort using simple random sampling. In Chapter 12, we developed a model that determined the group of variables that were most correlated with abundance of owls in 2007. Such a model could be used to stratify the HCP prior to conducting subsequent stratified random sampling of the owl population by completing a census of the surrogate variables prior to each survey. Prior to considering this model for such use, it needs to be validated with an independent dataset and its performance compared to other potential sources of information that could be used to construct strata.

There are various sources of information that may be considered for constructing strata, and we focused on those that may prove to be readily available, affordable, and statistically efficient (e.g., providing high precision). In Chapter 15, we discussed why the ideal variable for constructing strata is the variable itself (Cochran 1977:100), and in our case, that was the abundance of owls. If abundance remained spatially stable through time, at least for several years, then a practical alternative to using our model from Chapter 12 would be to use local abundance estimates from a prior census (Cochran 1977:100-101). However, if the population does not remain stable, the stratification would become inefficient and precision of population estimates would decrease (Cochran 1977:100-102). We originally proposed to develop a stratified random sampling

methodology from data collected during the 2007 breeding season, so it assumed a stable population. Given the changes in the owl population we reported in Chapter 16, abundance from a prior census may be an inefficient variable to stratify the HCP Study Area (Cochran 1977:100-102). Thus, a comparison of population estimates derived from constructing strata with this source of information to those from our correlative model may elucidate the relative efficiency of our model.

A third source of information that should be considered for constructing strata in the HCP Study Area comes from a full single survey at the beginning of the breeding season, immediately prior to sampling. As the population would likely be stable between this census and the subsequent sampling, this alternative could produce an extremely efficient method to construct strata from each year, possibly providing the most precise estimates of abundance (Cochran 1977:100-102). After this information is used to stratify the area, a cost-effective approach would involve conducting only 2 subsequent point-coordinate capture-recapture occasions in the randomly selected grid cells. Those 2 occasions could be combined with the original survey information in those cells, and this would constitute the 3 occasions recommended in chapter 6.

Our objectives here were to use an independent dataset to validate our stratified random sampling methodology and to compare the performance of our correlative model against these alternative methods of stratifying the HCP Study Area.

METHODS

To determine the most effective method of stratifying the HCP Study Area prior to future population sampling, we compared the precision of abundance estimates derived from simple random sampling and 3 methods of stratification applied with our stratified random sampling methodology across the HCP Study Area. We accomplished this using an independent dataset of local abundance estimates from a subsequent census of the population of grid cells in 2008 presented in Chapter 16. The 2008 census took place during the same period of the breeding cycle and followed the same survey routes, protocols, and analytical methods used to estimate abundance in grid cells in 2007. The methods of constructing strata that we considered were:

1. Our correlative model -- this model was the linear regression model with the spatial correlation coefficient that we determined to be best at predicting abundance from ancillary environmental variables (see Table 12.5), and was used in our development of a stratified random sampling methodology in Chapter 15. We used this model to assign 3x3 km grid cells into the 3 strata (low, medium, and high owl abundance) reported in Chapter 15. To mimic how this model could be applied to stratify grid cells for future surveys, we predicted abundance in each cell by applying the best model in Table 12.3 (which does not have a spatial covariate term) to the data on required data (i.e., total length of IID water conveyance structures, proportion of a grid cell in 2005 in alfalfa production, and number of burrows immediately prior to the intended survey in 2008). Next, we used those predicted abundances to estimate the mean number abundance out to 2

neighboring grid cells from each grid cell, and included this as the spatial data for fitting the best model with the spatial autocorrelation coefficient in Table 12.5.

2. A prior year's capture-recapture abundance estimates -- we used the point-coordinate capture-recapture estimates of local abundance from the 3 survey occasions to assign grid cells to the 3 strata.
3. A census comprised of a single survey occasion prior to sampling, but during the same prehatch stage of the breeding cycle -- we used the first survey occasion from our 2008 census of owls across the HCP Study Area to stratify individual grid cells to the 3 strata.

For simple random sampling and each method of constructing strata, we simulated random sampling of grid cells by bootstrapping 1,000 datasets from the complete population grid cells containing abundance estimates from the 2008 census without replacement. The total sample size for each simulation was 119, which was based on the minimum number of grid cells required to obtain an estimate <10% from the true population estimate. For each method of stratification, we used the method of determining strata boundaries and optimal allocation applied in Chapter 15. For the 3rd method of stratifying the HCP Study Area listed above, we mimicked how this method can be applied in future population surveys by using the first occasion to stratify and as the first of the three occasions in the randomly sampled grid cells.

For each method, we calculated the average and 95% confidence interval for each simulated population estimate. We compared the average of these simulated abundance estimates among the 4 methods and to the approximated true population size [3,557 (95% CI: 3,218-3,895)] reported in Chapter 16. We also compared the 95% confidence widths from each method to that surrounding the approximated true population size.

RESULTS

Simple random sampling and all 3 methods of constructing strata produced equivalent and unbiased estimates of the approximated true population size calculated from the independent census in 2008 (Figure 17.1). Stratified random sampling of strata constructed from a census comprised of a single survey occasion prior to sampling, but during the same prehatch stage of the breeding cycle, produced the most precise population estimates (Figure 17.1). The precision from this method of stratification (average 95% CI: 3,380-3,737) corresponded to a sampling error of 5% (approximately 178 territories) on either side of an unbiased population estimate, and translated to a 10% minimum detectable change in the population.

The precision of population estimates from stratified random sampling of strata constructed with a prior year's capture-recapture abundance estimates was lower than that of the previous stratification method (average 95% CI: 3,325-3,788; Figure 17.1). This level of precision represented a sampling error of 7% on either side of an unbiased population estimate and a 15% minimum detectable change in the population.

Stratified random sampling from strata constructed with our correlative model that used alfalfa, available burrows, and spatial structure provided the poorest precision among the 3 methods of stratification (average 95% CI: 3,202-3,911). The 10% precision on either side of the unbiased population estimate would allow a 20% minimum detectable change in the population.

Simple random sampling provided the poorest precision (Figure 17.1). Its level of precision (95% CI: 3,174-3,949) represented 11% error on either side of an unbiased population estimate, which would provide a 22% minimum detectable change in the population.

Strata constructed from a census comprised of a single survey occasion prior to sampling, but during the same prehatch stage of the breeding cycle or from a prior year's capture-recapture abundance estimates provided a marked improvement in precision over that attainable from simple random sampling or using the correlative model to determine strata membership (Figure 17.1).

CONCLUSIONS AND RECOMMENDATIONS

Our results validate our optimally allocated stratified random sampling methodology developed in Chapter15. We demonstrated that this methodology can greatly improve the precision of unbiased population estimates of male Burrowing Owl territories in the HCP Study Area, given the use of an efficient method of constructing strata. We also showed that this precision improved the statistical power of detecting a change in the population, thereby allowing a smaller minimal level of detectable change.

We further demonstrated that the performance of our stratified random sampling methodology is dependent on the efficiency of the strata constructed prior to a population survey. A prior year's capture-recapture abundance estimates provided 15% minimal detectable change in the population. Although this level of change may appear reasonable, it is unrealistic to expect that data from capture-recapture surveys would be available for all grid cells from the year preceding each annual survey when the overall objective is to conduct capture-recapture surveys in only a sample of the grid cells each year. Additionally, given the change in the population that we reported in Chapter 16, it would be unreasonable to consider information from such a census from ≥ 2 years prior to a population survey.

The poor performance of our correlative model for constructing strata may have been due in part to the low amount of variation in owl abundance that the model explained (see Chapter 12). The inefficiency of this stratification method indicated that the variables in the model inadequately predicted local owl abundances in the 2008. This was surprising given its predictive ability we demonstrated with the k-fold cross validation procedure in Chapter 12. One reason for this poor performance may have been the marked change in the population, which was of a degree that likely violated the assumption of a relatively stable population. Nonetheless, its poor performance with the independent dataset suggests that factors other than those in the model may be regulating or limiting the local

abundances of Burrowing Owls. Thus, given the lack of information on this subject at this time, we also suggest that it is currently inappropriate to consider surrogates of owl abundance for stratifying the HCP Study Area.

Strata constructed from a census comprised of a single survey occasion prior to sampling, but during the same prehatch stage of the breeding cycle, provided the most precise estimates and smallest level of detectable change in the population (10%). As we described in the introduction, the information needed to achieve this efficient method of constructing strata would originate from a full single survey, constituting a census, prior to, but during the same breeding season of the anticipated sampling. We believe this would provide the most reliable population estimates in the most cost-effective manner because the results from a prior census could be used in the following ways: 1) to stratify the HCP Study Area, as no other methods of stratifying are as reliable or efficient, 2) as the first of 3 required occasions (see Chapter 6) in the randomly selected grid cells, 3) to calculate the growth rates of local populations described in Chapter 19, as no other data would be available for calculating such rates, 4) as the basis for estimating the relative distribution and abundances across the HCP Study Area, and 5) to map out the exact locations of nests throughout the HCP Study Area. In the absence of the complete survey, our optimally allocated stratified random sampling methodology will become less efficient each year, lowering the minimum detectable level of change. Because it would represent the only source of information to produce the results described under points 3-5, its absence would prevent the acquisition of these results which are important for understanding where to direct adaptive management activities across the HCP Study Area.

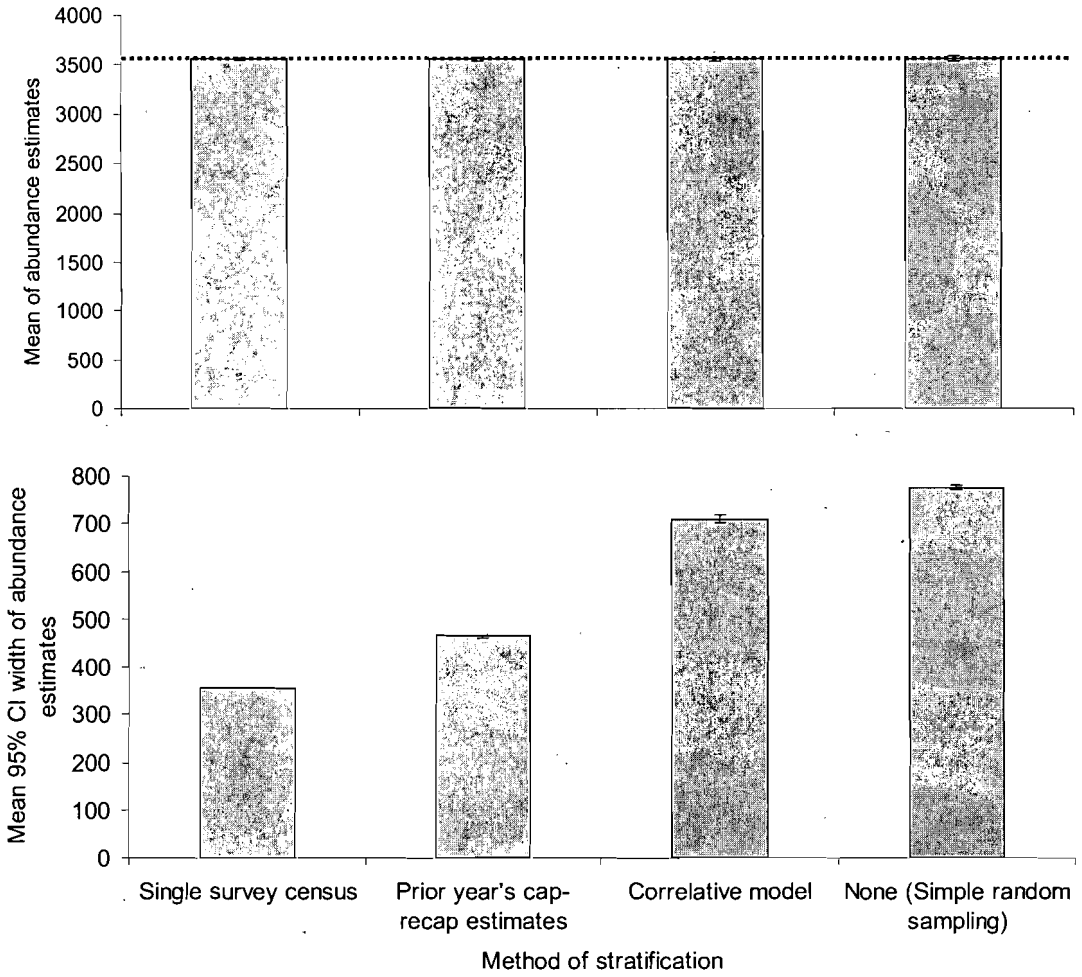


Figure 17.1. Mean simulated population (A) and 95% confidence interval width (B) estimates under 3 methods of stratifying grid cells and simple random sampling in the HCP Study Area. Datasets were simulated samples bootstrapped from the complete 2008 survey data. Dotted line represents true population size approximated by summing the point-coordinate capture-recapture abundance estimates from the entire the population of 274 grid cells. All estimates assume negligible measurement error.

Chapter 18

RECOMMENDED SAMPLING METHODOLOGY WITH OPTIMAL ALLOCATION OF EFFORT TO SURVEY FOR AND ESTIMATE MALE BURROWING OWL TERRITORY ABUNDANCE

JEFFREY A. MANNING

ABSTRACT. In this chapter, I provide recommendations for the sampling methodology with optimal allocation of effort to survey for and estimate male Burrowing Owl territory abundance. For conducting surveys in grid cells, I recommended that: 1) the point-coordinate capture-recapture technique should be used, 2) point locations of owls should be recorded following the methods previously described while avoiding the relatively hot afternoon period, 3) three point-coordinate capture-recapture survey occasions should be completed, and 4) a single survey pass on one side of all above-ground drains and canals should be conducted during each point-coordinate capture-recapture occasion. For sampling, I recommended that: 1) sampling should follow the optimally allocated stratified random sampling methodology developed in Chapter 15 and validated in Chapter 17, 2) samples should be drawn from the standardized sampling grid of 274 grid cells, 3) strata should be constructed from a census comprised of a single survey occasion prior to sampling, but during the same prehatch stage of the breeding cycle, 4) a minimum required sample size should be determined from Table 15.1, and 5) stratum boundaries and optimal allocation of sampling units should be determined based on equations in Chapter 15 once a sample size is chosen and the single survey census completed. The construction of strata from a census comprised of a single survey occasion prior to sampling, but during the same prehatch stage of the breeding cycle was shown to produce the most precise estimates and smallest level of detectable change in the population (10%) compared to other methods. The information needed to achieve this efficient method would not only provide the most reliable population estimates, but could also be used: 1) to stratify the HCP Study Area, as no other methods of stratification are as reliable or efficient, 2) as the first of 3 required occasions (see Chapter 6) in the randomly selected grid cells, 3) to calculate the growth rates of local populations described in Chapter 19, as no other data would be available for calculating such rates, 4) as the basis for estimating the relative distribution and abundances across the HCP Study Area, and 5) to map out the exact locations of approximately 70% of nests throughout the HCP Study Area.

INTRODUCTION

The success of a long-term population monitoring program depends on an efficient sampling design that minimizes the required sample size, optimizes the allocation of survey effort, and reduces costs while maintaining high levels accuracy at all stages of the survey. Monitoring programs across large landscapes generally involve sampling areas from a larger population of areas suitable for or occupied by the species of interest and surveying for the species in each of the selected areas. Sampling error occurs when areas are randomly sampled from the population of available areas (e.g., a different

random sample of areas at the same time could yield a different estimate and level of precision) and measurement error occurs during a survey of a selected area (e.g., animals were available but undetected or present but unavailable). Only monitoring programs that are based on known levels of measurement error and sampling error can yield reliable population estimates for making informed management decisions.

In the previous chapters, I considered these important aspects of monitoring programs. I developed retrospective studies, field experiments, simulations, and validations with independent datasets to elucidate various aspects of Burrowing Owl natural history in the HCP Study Area and to examine the statistical properties of population estimates from various survey and sampling methods. Based on the results from those studies, I provide the following recommended sampling methodology for monitoring the Burrowing Owl population in the HCP Study Area.

CONCLUSIONS AND RECOMMENDATIONS

Surveys

An accurate estimate of population size can be obtained with sampling designs that account for the size, shape, number, and placement of sampling units across areas where abundance is unevenly distributed (Caughley 1977:27; Williams et al. 2002:247), like that of owls in the HCP Study Area. These designs generally assume that population counts in sample units are without measurement error. Because measurement error probably cannot be completely eliminated (Steenhof and Kochert 1982, Fraser et al. 1983), it is critical that measurement error is minimized during surveys. Measurement error can be reduced by using standardized protocols, trained and skilled observers, reliably accurate survey methods, careful timing to reduce problems with availability, and reliable analytical methods.

Based on the importance of minimizing measurement error, I recommend the following:

1. The point-coordinate capture-recapture technique should be used to conduct surveys and construct encounter histories in grid cells. In Chapter 5, this technique was shown to produce accurate estimates of population size and be cost effective when many owls are present. However, as discussed in Chapter 10, the performance of capture-recapture is slightly reduced with small sample sizes (small numbers of owls within grid cells). A cost-effective alternative that may not have this problem would be a single survey technique that corrects for visibility and availability biases, but such a technique has not yet been developed for Burrowing Owls. Until such techniques are developed and proven to produce reliable population estimates, the point-coordinate capture-recapture technique is the most cost-effective method of producing estimates with negligible error.

2. Point locations of owls should be recorded following the methods described in Chapter 7 and Appendix II, including the avoidance of surveying during the relatively hot afternoon period and surveying from a vehicle of same make and model (Ford Escape). The methodology assumes that that this is the only make and model of vehicle used for conducting surveys. This is because the number of

occasions, and other aspects of the survey methods, is based on empirical information derived from observations from the view shed afforded by that vehicle. Use of an alternative vehicle for conducting surveys may compromise the accuracy and reliability of population estimates and their associated levels of precision.

3. Three point-coordinate capture-recapture survey occasions should be completed in each grid cell to estimate abundance of male territories. In Chapter 6, this number of occasions was demonstrated to the minimum number needed to produce unbiased estimates. As shown in Chapter 10, applying 3 survey occasions with this technique should detect approximately 98% of the owls. The capture-recapture models should correct for the remaining 2%.

4. A single survey pass on one side of all above-ground drains and canals should be conducted during each point-coordinate capture-recapture occasion. This is based on the findings in Chapters 3 and 4. However, where ≥2 water conveyance structures parallel multiple access roads within a single right-of-way and the field of view could be compromised by distance between the water conveyance structures (roughly ≥60 m) or topography, a survey pass should be conducted on >1 of the parallel roads to ensure complete survey coverage of the right-of-way while care is taken to not survey the same water conveyance structure twice (i.e., each water conveyance structure should be surveyed from only one side). Care should also be taken to note the location of owls detected on the first pass to ensure that the same owl is not double counted during the 2nd pass in the right-of-way.

Sampling

Because abundance of owls is expected to be unevenly distributed across the HCP Study Area, an accurate estimate of population size can be obtained using sampling designs that account for the size, shape, number, and placement of sampling units (Caughley 1977:27; Williams et al. 2002:247). This is a critical issue in population monitoring because increased precision translates to an increase in the ability to detect changes in population size among years. Imprecise estimates only allow for detection of large changes.

Based on the needs to minimize sampling error and reduce costs, I recommend the following sampling methodology for each population survey:

1. Sampling should follow the optimally allocated stratified random sampling methodology developed in Chapter 15 and validated in Chapter 17.

2. Samples should be drawn from the same standardized sampling grid of 274 grid cells established in Chapter 9.

3. Strata should be constructed prior to sampling by using the equations in Chapter 15 with data from a census comprised of a single survey occasion prior to sampling, but during the same prehatch stage of the breeding cycle. In Chapter 17, this method of stratification was shown to provide the most precise estimates and smallest level of detectable change in the population

(10%) compared to other methods. As described in that chapter, the information needed to achieve this efficient method would not only provide the most reliable population estimates, but it may also represent the most cost-effective source of information that could be used to answer numerous questions that need to be answered to achieve accurate population estimates. As such, this single dataset could be used: 1) to stratify the HCP Study Area, as no other methods of stratifying are as reliable or efficient, 2) as the first of 3 required occasions (see Chapter 6) in the randomly selected grid cells, 3) to calculate the growth rates of local populations described in Chapter 19, as no other data would be available for calculating such rates, 4) as the basis for estimating the relative distribution and abundances across the HCP Study Area, and 5) to map out the exact locations of approximately 70% of nests throughout the HCP Study Area. The use of this information as the first of 3 occasions will lead to a few-week time lag between the first and second occasions, and this differs from how the data were collected originally in developing the point-coordinate capture-recapture technique. Although we suspect that this technique should be robust to this, such time lags may introduce changes in the space use of individuals over the course of surveys, and may introduce an unknown level of error into the derived estimates, although we expect that this error would be small.

4. Due to edge effects (i.e., Burrowing Owls occupy home ranges that can be bisected from grid cell boundaries), the 2nd and 3rd surveys must be extended 110 m beyond the boundary of all sampled grid cells.

5. Minimum required sample size should be determined from Table 15.1. Because the choice of a minimum detectable level is a value judgment that defines an acceptable level of risk and determines the cost of surveys, it is difficult for a statistician to make such a recommendation. In lieu of providing a recommended level, I provided a range of statistically reliable estimates of minimum detectable levels of population change related to levels of sampling across the HCP Study Area. These statistically reliable estimates enable the IT to determine the appropriate level of sampling for their chosen minimum detectable level of population change. As long as the sampling effort corresponding to a chosen level of change is completed the same way each time, the results between population surveys should be comparable and statistically reliable (as described in Chapter 17). If that level of change is maintained in all subsequent population surveys, regardless of the level of change that is decided on, the methodology recommended above will still be valid.

   An important assumption associated with using the information in Table 15.1 to determine the minimum required sample size for a chosen level of population change is that the variability in abundance among the 274 grid cells in the following population survey is equivalent to or smaller than that found in 2007 (see Chapter 10). This is because the calculations used to

create that table were derived from the empirical data collected in 2007. If this assumption is not met (i.e., the variability on a given year is larger), the finite adjusted sample sizes listed in Table 15.1 will produce population estimates that can be farther from the true mean than the distances listed in the table. Essentially, increased variability will lower the power of a given finite adjusted sample size.

The assumption described above should be tested prior to the next population survey by calculating a measure of variability. An assessment of the variability before the next population sampling can be attained from the single survey occasion prior to sampling, but during the same prehatch stage of the breeding cycle (referenced under C above). Since the population of grid cells will always remain constant at 274 cells, a standard deviation is sufficient, which was also provided for the 2007 data in Table 10.1 (high St. Dev during a single survey occasion = 10.7). The single survey prior to the next population survey can be used to estimate the standard deviation among grid cells and comparing it to from 2007. If the standard deviations remain relatively similar, the relationships between finite adjusted sample sizes and distance from the true mean in Table 15.1 will be correct and the sample size chosen for 2007 can be applied to that sampling effort. If the variability is greater, than new a table of minimum required sample sizes will have to be created by recalculating those estimates using the calculation presented in Chapter 15. If the standard deviation does increase for any subsequent population survey, the sample size would have to be determined from either a newly created table or one of the previously constructed tables associated with an equivalent standard deviation. This should be carried out prior to each subsequent survey, thereby adjusting the sample size whenever the variance changes.

Applying this important part of the sampling methodology prior to each subsequent population survey will result in sample sizes that may vary some among years, but the power of detecting a desired level of change between population estimates would remain constant. This latter point is critical to ensure reliable and comparable estimates for detecting changes in the population.

6. Once the sample size and stratum boundaries are determined, the optimal allocation of sampling units should be based on the equations in Chapter 15.

The above recommendations should be implemented in the following sequence:

1. Single survey of entire HCP Study Area

2. Strata determined from 1

3. Determine the minimum required sample size. To do this, first calculate the standard deviation determined from 1. if the st dev is similar to that from a previous survey, use the table from that survey. If not, recreate table.

4. Determine optimal allocation based on new strata, new sample size, and new strata-specific variances

5. Randomly sample grid cells according to 4

6. Conduct surveys

7. Create point-coordinate capture-recapture encounter histories for all randomly selected grid cells using:

    a. All 3 survey occasions (including the first one consisting of the complete survey
    b. The point-coordinate capture-recapture analytical procedures described in Chapter 5, including the use of the 55-m radius MMDM as the buffer, to construct territory centroids and encounter histories
    c. The sampling grid to assign centroids to their corresponding grid cells (only for those centroids that lie within the boundary of a sampled grid cell)

8. Compute stratified random sampling estimates of population size and associated level of precision

The above recommendations for sampling should be applied for each population survey e.g., each year). They also are based on using the point-coordinate capture-recapture technique, which is dependent on completing 3 survey occasions to attain a single population estimate. This multiple number of survey occasions provides the opportunity to conduct a complete single occasion as the basis for constructing strata (as described above), from which to draw a stratified random sample from the standardized sampling grid. However, if a reliable survey technique is developed that can correct for visibility and availability bias from a single survey occasion, it could be embedded into these methods in lieu of the point-coordinate capture-recapture technique. If this is done, the stratification method presented here will be unavailable because a prior complete survey will not be available for constructing strata. Thus, in order to ensure that such an alternative approach would continue to be able to detect the desired minimum level of population change, it would warrant revisiting the sampling methodology.

2007 and 2008 Population Estimates for Comparison Purposes

Although we conducted complete censuses of the HCP Study Area in 2007 and 2008, future surveys are anticipated to be completed by sampling the population. To provide

estimates for these previous years that are comparable to those from future surveys, I provide estimates of abundance with measures of variance based on the recommended sampling and survey methods. The two estimates, which were obtained from the bootstrapped stratified random sampling of the 274 grid cells, are:

2007: 4,879 territories (95% CI: 4,692-5,065)
2008: 3,557 territories (95% CI: 3,370-3,743)

This sampling used the recommended minimum required sample size and optimal allocation. These abundance estimates were closest to the approximated true population size derived from summing all 274 grid cells, and thus represent sufficient samples. But, they provide confidence intervals that were estimated from the sampling variance that is comparable to those to be obtained from future sampling.

Chapter 19

DEMONSTRATED USE OF ABUNDANCE ESTIMATES FOR CALCULATING LOCAL FINITE RATES OF POPULATION CHANGE

JEFFREY A. MANNING

ABSTRACT. I provide a demonstration on the use of local abundance estimates for calculating local finite rates of population change that could be used to direct adaptive management actions to specific areas in the HCP Study Area.

INTRODUCTION

Two fundamental goals of the HCP are to determine the abundance and distribution of Burrowing Owls and to monitor the population's annual growth rate in order to make decisions on when adaptive management actions should take place. In the event that a marked decline is detected, it is equally important to determine where to strategically apply management actions in the HCP Study Area. One approach would be to strategically target local areas in the HCP to attain the highest ecological benefit to the Burrowing Owl population for a given expenditure of effort and cost.

Here I propose such an approach that capitalizes on abundance estimates and the spatial variability in owl abundance across the HCP Study Area rather than demographic information. When a marked decline is detected, a beneficial use of local estimates of abundance would be to evaluate Burrowing Owl population growth rates in local areas across the HCP. Population growth rates are typically estimated using demographic (fecundity and survival) or census data over time (Sibly et al. 2003:12). Censuses of high-density populations have greater statistical power of detecting a population decline than demographic studies (Taylor and Gerrodette 1993). Because these two methods of estimation can give similar values, as shown in studies of the spotted owl (*Strix occidentalis caurina*; Lande 1988, Burnham et al. 1996), the use of Burrowing Owl abundance estimates can satisfy the need to monitor the population's rate of change during the interim until the results from the demographic study required under the HCP become available. I demonstrate how abundance estimates from point-coordinate capture-recapture estimates of local abundance (or a single survey occasion as recommended in Chapter 18) can be used to calculate local population growth rates for Burrowing Owls in the HCP Study Area and discuss how such local rates can be used for identifying priority areas within the HCP Study Area to strategically direct adaptive management actions.

METHODS

Given the data collected in 2007 (Chapter 10) and 2008 (Chapter 16), it is evident that the local abundances have shifted in the HCP Study Area (Figure 19.1). Such temporal

variation among local areas between the 2007 and 2008 breeding seasons can be used to calculate and compare local growth rates. I computed a finite rate of change (λ) in the population of male Burrowing Owl territories between the 2007 and 2008 breeding seasons in local areas (3x3 km grid cells) in the HCP Study Area. Following Caughley (1977:51), I calculated λ as:

$$\lambda = \frac{N_{t+1}}{N_t}. \qquad \text{Equation 18.1}$$

RESULTS

Under the hypothetical example that a marked decline in male territory abundance was detected in the HCP Study Area, I calculated finite rates of change across the HCP Study Area to assess the local changes, and these ranged from 0 to 7.0 (Figures 19.2 and 19.3). The abundance of male Burrowing Owl territories declined in 75% (206) of the 274 local grid cells, with 23% (62) of them declining >50% (Figures 19.3 and 19.4).

CONCLUSIONS AND RECOMMENDATIONS

The reliable estimates of abundance that can be obtained from the recommended survey and sampling methodology can provide accurate rates of local population changes in the HCP Study Area. By using the local 3x3 km grid cells to calculate local rates of change, I demonstrated how to identify differences in that important demographic rate across the HCP Study Area. Such spatially explicit information can help facilitate the application of management actions by quickly identifying geographic areas according to a specific rate of change. I provided the example of identifying where local population rates declined >50%. If that cutoff was chosen for targeting management actions, the locations for such priority areas would be readably attainable from the previously collected population abundance data.

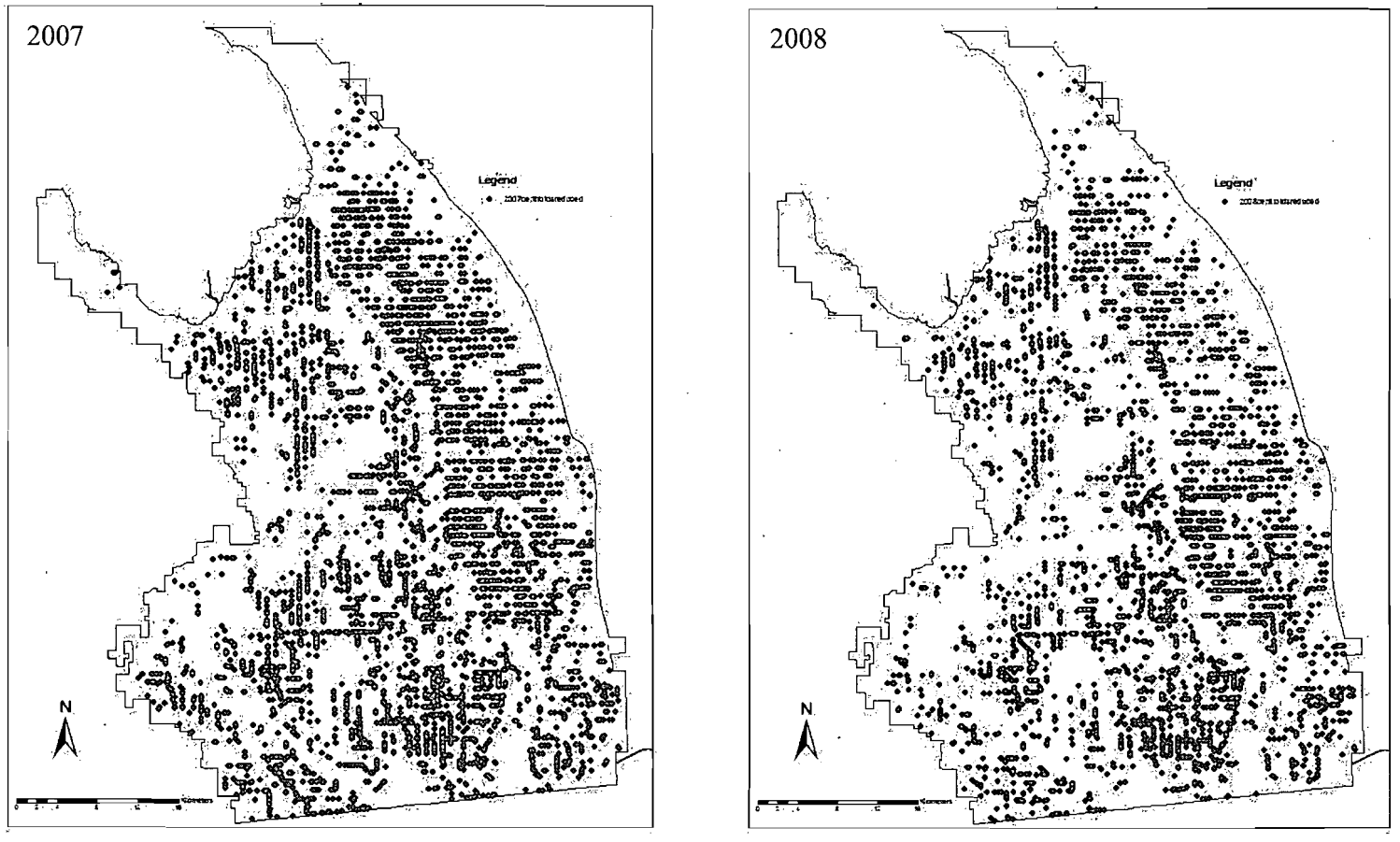


Figure 19.1. Locations of male Burrowing Owl territories in the 2007 and 2008 breeding seasons, determined from 3 point-coordinate capture-recapture survey occasions in the HCP Study Area, Imperial County, California.

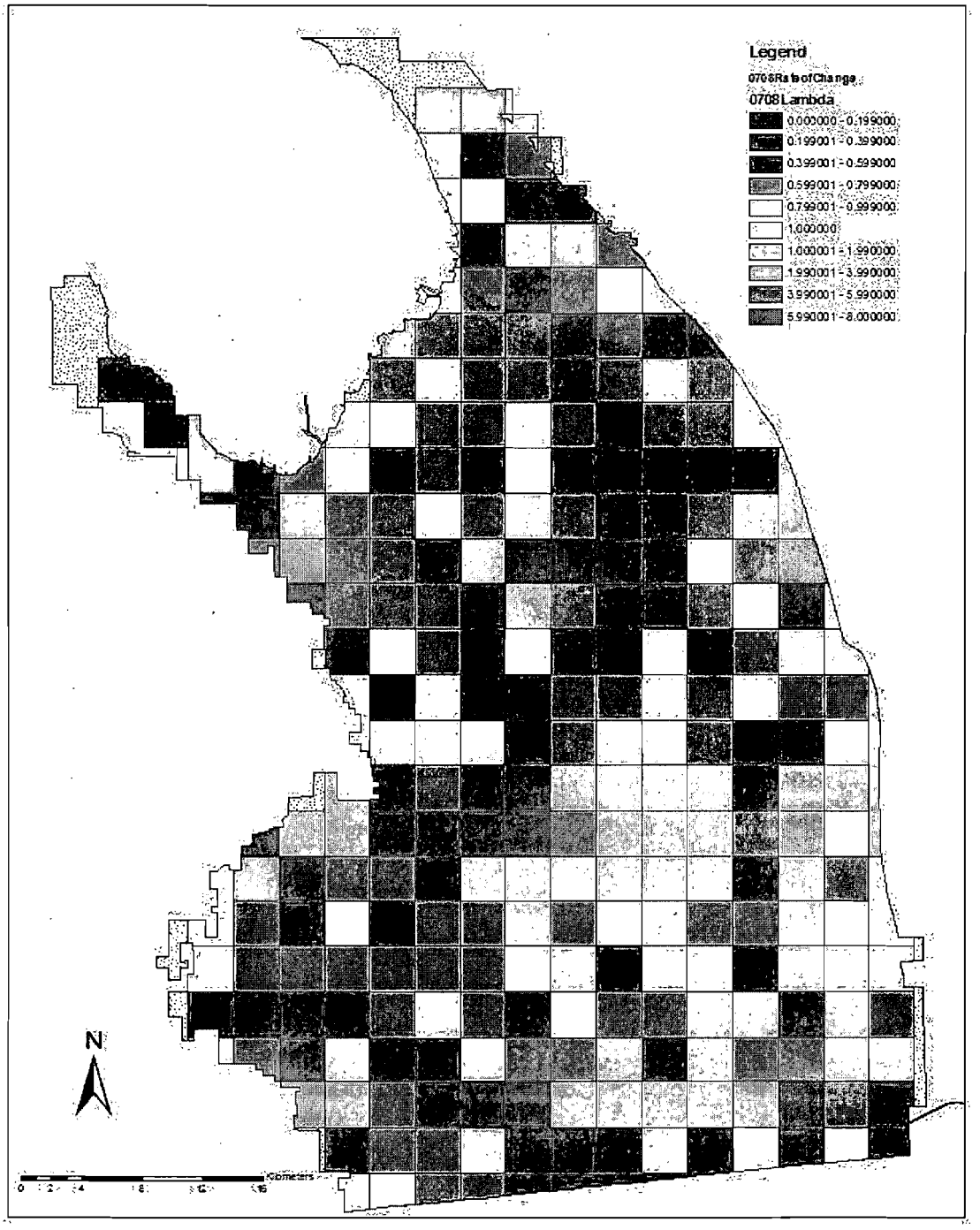


Figure 19.2. Finite rates of annual change (λ_{local}) in abundance of male Burrowing Owl territories in local areas (3x3 km grid cells) of the HCP Study Area between the 2007 and 2008 breeding seasons. Stippled areas were not surveyed due to absence of above-ground water conveyance structures.

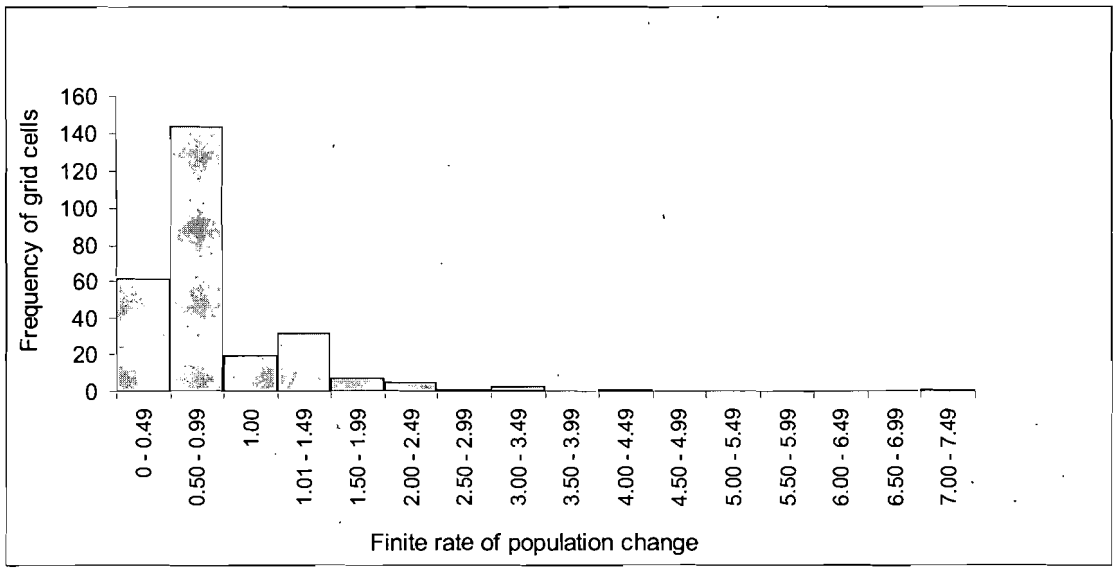


Figure 19.3. Frequency of local grid cells according to their finite rate of change (λ_{local}) in the population of male Burrowing Owl territories between the 2007 to 2008 breeding seasons in the HCP Study Area.

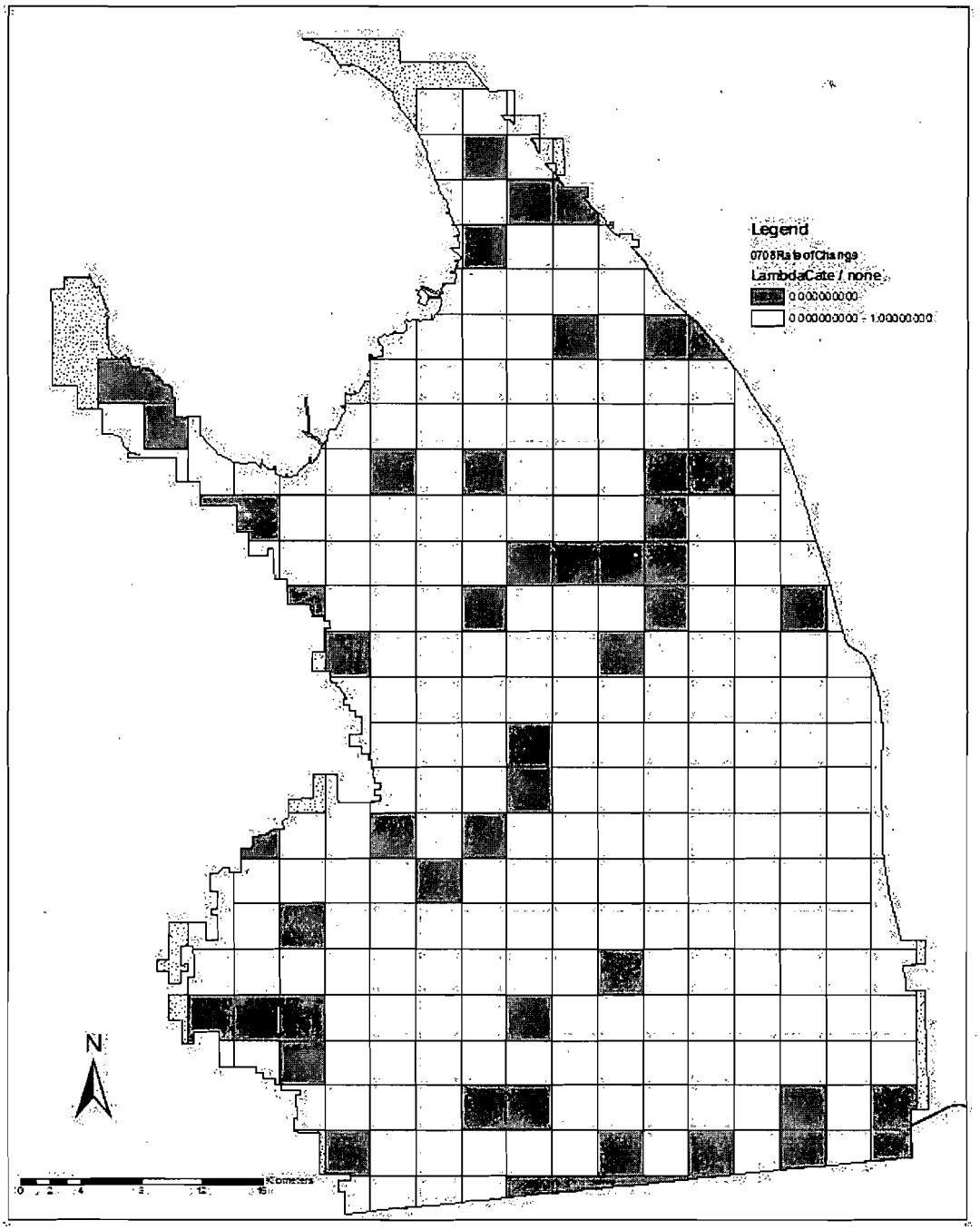


Figure 19.4. Example of finite rates of change with a cutoff = 0.5, demonstrating the locations of local areas where the lowest negative rates occurred between the 2007 and 2008 breeding seasons in the HCP Study Area, Imperial County, California. Stippled areas were not surveyed due to absence of above-ground water conveyance structures.

Chapter 20

RECOMMENDED FUTURE RESEARCH DIRECTIONS

JEFFREY A. MANNING

INTRODUCTION

The following is a brief list of recommended future research directions divided into two sections: 1) those intended to improve the accuracy and reduce costs of population monitoring, and 2) those intended to improve the understanding of the status of the Burrowing Owl population and factors that potentially limit or regulate it.

Recommended Research to Improve the Accuracy and Reduce Costs of Population Monitoring

1. Design and validate a single-survey method that accounts for visibility and availability bias (e.g., sightability) and can produce precise, unbiased estimates of male territory abundance in the HCP.

2. Investigate the effects of variable space use over time between the single survey census at the beginning of the season and subsequent capture occasions on the accuracy of point-coordinate capture-recapture estimates.]

3. Investigate more refined predictors of abundance for stratification purposes
    a. More accurate and specific maintenance data
    b. More accurate crop data

Recommended Research to Improve the Understanding of the Status of the Burrowing Owl Population and Factors that Potentially Limit or Regulate it

1. Continued annual monitoring, particularly given the change in owl abundance we identified between 2007 and 2008.

2. Investigate age-specific demographic rates (mortality, productivity) in the HCP Study Area, to direct adaptive management (Currently, the population estimates presented in this report can only direct management to a specific grid cells, but not to a targeted age class or causal factors of local declines).

3. Determine what portion of the breeding population is migratory.
    a. If migrants comprise a biologically significant component of the breeding population, a study of mortality in their wintering and migration areas is needed.

4. Determine the southern extent of this breeding population (e.g., does it extend across the International Border with Mexico).

a. If the breeding population extends into Mexico, determine the rate of exchange across the International Border.

5. Investigate spatial and temporal patterns in the numerical response of owls to crop activities and IID's maintenance activities.

6. Investigate the effects of changes in agricultural practices (due to reduced water sources) on the fitness of owls.

Recommended citation:
Manning, J. A. 2009. Burrowing Owl population size in the Imperial Valley, California: survey and sampling methodologies for estimation. Final report to the Imperial Irrigation District, Imperial, California, USA, April 15, 2009.

LITERATURE CITED

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 267-281 in B. Petran and F. Csaki, editors. International Symposium on Information Theory. Second edition. Akademiai Kiado, Budapest.

Arizona Game and Fish Department. 2007. Burrowing owl management guidelines for municipalities in Arizona. Arizona Game and Fish Department, Phoenix, USA.

Atkinson, A. J., P. C. Trenham, R. N. Fisher, S. A. Hathaway, B. S. Johnson, S. G. Torres, and Y. C. Moore. 2004. Designing monitoring programs in an adaptive management context for regional multiple species conservation plans. U.S. Geological Survey Technical Report. Western Ecological Research Center, Sacramento, California.

Bailey, R. G. 1994. Ecological classification for the United States. USDA Forest Service, Washington DC.

Bloom, P. H. 1987. Capturing and handling raptors, p. 99-123. *In* B. A. Millsap, K. W. Cling, B. Giron Pendleton and D. A. Bird [eds.]. Raptor management techniques manual. National Wildlife Federation Science Technical Series #10. National Wildlife Federation, Washington, D.C.

Bloom, P. H., W. S. Clark, and J. W. Kidd. 2007. Capture techniques, p. 193-219. *In* D. M. Bird and K. L. Bildstein [eds.]. Raptor research and management techniques. Hancock House Publishers, Surrey, British Columbia.

Blundell, G. M., J. A. K. Maier, and E. M. Debevec. 2001. Linear home ranges: effects of smoothing, sample size, and autocorrelation on kernel estimates. Ecological Monographs 71:469-489.

Brenckle, J. F. 1936. The migration of the western burrowing owl. Bird-Banding 7:166-168.

Burnham K.P., and D.R. Anderson. 2002. Model selection and multimodel inference: A practical information-theoretic approach. 2nd ed. Springer-Verlag Inc., New York, USA.

Burnham, K. P., D. R. Anderson, G. C. White. 1996. Meta-analysis of vital rates of the northern spotted owl. Studies in avian biology 17:92-101.

Burt, W. H. 1943. Territoriality and home range concepts as applied to mammals. Journal of Mammalogy. 475 24, 346-352.

California Burrowing Owl Consortium. 1997. Burrowing owl survey protocol and mitigation guidelines. Raptor Research Report 9:171–177.

Catlin, D. H. and D. K. Rosenberg. 2006. Nest destruction associated with mortality and dispersal of Burrowing Owls in the Imperial Valley, California. The Southwest Naturalist 51:406-409.

Caughley, G. 1977. Analysis of vertebrate populations. The Blackburn Press, New Jersey, USA.

Chamberlin, T. C., 1890. The method of multiple working hypotheses. Science 15:92-97.

Chamberlin, T. C., 1965. The method of multiple working hypotheses. Science 148:754-759.

Chao, A. 1989. Estimating the population size for sparse data in capture-recapture experiments. Biometrics 45:427-38.

Cleveland, W. 1979. Robust locally weighted regression and smoothing scatterplots. Journal of the American Statistical Association 74:829-836

Cleveland, W. and S. Devlin. 1988. Locally weighted regression: An approach to regression analysis by local fitting. Journal of American Statistical Association 83:596-610.

Cochran, W. G. 1977. Sampling techniques, 3rd ed. John Wiley and Sons, New York, USA.

Collister, A. 1967. Simple noose trap. Western Bird Bander 42:4.

Conway, C. J., and J. Simon. 2003. Comparison of detection probability associated with burrowing owl survey methods. Journal of Wildlife Management 67:501–511.

Conway, J. C., V. Garcia, M. D. Smith, and K. Hughes. 2008. Factors affecting detection of burrowing owl nests during standardized surveys. Journal of Wildlife Management 72:668-696.

Cooch, E. 1999. First steps with Program MARK: linear models. Source: http://welcome.warnercnr.colostate.edu/class_info/fw663/Mark.html.

Coulombe, N. H. 1971. Behavior and population ecology of the burrowing owl, *Speotyto cunicularia*, in the Imperial Valley, California. The Condor 73:162-176.

Cressie, N. A. 1991. Statistics for Spatial Data. John Wiley & Sons, Inc., New York, NY, USA.

Desante, D. F., E. D. Ruhlen, and D. K. Rosenberg. 2004. Density and abundance of burrowing owls in the agricultural matrix of the Imperial Valley, California. Studies in Avian Biology 27:116-119.

Devijver, P. A., and J. Kittler. 1982. Pattern Recognition: A Statistical Approach, Prentice-Hall, London.

Diefenbach, R. D., M. R. Marshall, J. A. Mattice, and D. W. Brauning. 2007. Incorporating availability for detection in estimates of bird abundance. The Auk 124:96-106.

Diniz-Filho, J. A. F., and M. P. d. C. Telles. 2002. Spatial autocorrelation analysis and the identification of operational units for conservation in continuous populations. Conservation Biology 16:924-935.

Fortin, M.-J., and M. Dale. 2005. Spatial Analysis: A Guide for Ecologists. Cambridge University Press, Cambridge, UK.

Fraser, J. D., L. D. Frenzel, J. E. Mathisen, F. Martin, and M. E. Shough. 1983. Scheduling bald eagle reproduction surveys. Wildlife Society Bulletin 11:13-16.

Gervais, J. A., D. K. Rosenberg, and R. G. Anthony. 2003. Space use and pesticide exposure risk of male Burrowing Owls in an agricultural landscape. Journal of Wildlife Management 67:155-164.

Green, G. A. 1983. Ecology of breeding burrowing owls in the Columbia basin, Oregon. M.S. Thesis. Oregon State University, Corvallis, Oregon.

Green, G. A., and R. G. Anthony. 1989. Nesting success and habitat relationships of burrowing owls in the Columbia Basin, Oregon. Condor 91:347-354.

Haining, R. 2003. Spatial Data Analysis: Theory and Practice. Cambridge University Press, Cambridge, UK.

Hanley, J. A. and B. J. McNeil. 1982. *The Meaning and Use of the Area under a Receiver Operating Characteristic (ROC) Curve.* Radiology 143: 29-36.

Haug, E. A. 1985. Observations on the breeding ecology of Burrowing Owls in Saskatchewan. M.S. thesis. University of Saskatchewan, Saskatoon, Saskatchewan.

Haug, E. A. and L. W. Oliphant. 1990. Movements, activity patterns, and habitat use of burrowing owls in Saskatchewan. Journal of Wildlife Management 54:27-35.

Haug, E. A., and A. B. Didiuk. 1993. Use of recorded calls to detect burrowing owls. Journal of Field Ornithology 64:188–194.

Haug, E. A., B. A. Millsap, and M. S. Martell. 1993. Burrowing Owl (*Speotyto cunicularia*), p. 1-18. *In* A. Poole, and F. Gill [eds.]. The birds of North America, No. 61. Academy of Natural Sciences, Philadelphia, PA, and American Ornithologists' Union, Washington, D.C.

Heagerty P. J., T. Lumley, and M. S. Pope. 2000. Time-dependent ROC curves for censored survival data and a diagnostic marker. Biometrics 56:337–344.

Heywood, J. S. 1991. Spatial analysis of genetic variation in plant populations. Annual Revue of Ecology, Evolution and Systematics 22:335-355.

Hines, J. E. 2006. PRESENCE2 – Software to estimate patch occupancy and related parameters. USGS-PWRC. Available at: http://www.mbr-pwrc.usgs.gov/ software/presence/html

Holroyd, G. L., R. Rodriguez-Estrella, and S. R. Sheffield. 2001. Conservation of the burrowing owl in western North America: issues, challenges, and recommendations. Journal of Raptor Research 35:399–407.

Horne, J. S., and E. O. Garton. 2006. Likelihood cross-validation versus least squares cross-validation for choosing the smoothing parameter in kernel home-range analysis. Journal of Wildlife Management 70: 641-648.

Hosmer, D.W, Jr. and S. Lemeshow. 1989. *Applied Logistic Regression*, John Wiley & Sons, Inc., New York, USA.

Ihaka, R., and R. Gentleman. 1996. R: a language for data analysis and graphics. Journal of Computational and Graphical Statistics 5:299–314.

James, P. C., and R. H. M. Espie. 1997. Current status of the burrowing owl in North America: an agency survey. Raptor Research Report 9:3–5.

Jones, B and M. G. Kenward. 1989. Design and analysis of cross-over trials. Chapman and Hall, New York, New York, USA.

Kendall, W.L. 1999. Robustness of closed capture-recapture methods to violations of the closure assumption. Ecology 80:2517-2525.

Klute, D. S., L. W. Ayers, M. T. Green, W. H. Howe, S. L. Jones, J. A. Shaffer, S R. Sheffield, and T. S. Zimmerman. 2003. Status assessment and conservation plan for the western Burrowing Owl in the United States. U.S. Department of Interior, Fish and Wildlife Service, Biological Technical Publication FWS/BTP-R6001-2003, Washington, D.C., USA.

Kuehl, R. O. 1994. Statistical principles of research design and analysis. Duxbury Press, Belmont, California, USA.

Laird, N. M. and J. H. Ware. 1982. Random-effects models of longitudinal data. Biometrics 38:963–974.

Lande, R. 1988. Demographic models of the northern spotted owl (*Strix occidentalis caurina*). Eocologia 75:601-607.

Legendre, P., and M.-J. Fortin. 1989. Spatial pattern and ecological analysis. Vegetatio 80:107-138.

MacCracken, J. G., D. W. Uresk, and R. M. Hansen. 1985. Vegetation and soils of burrowing owl nest sites in Conata Basin, South Dakota. The Condor 87:152-154.

MacKenzie, D. and L. Bailey. 2004. Assessing fit of site occupancy models. Journal of Agricultural, Biological and Ecological Statistics 9:300-318.

Martin, D. J. 1973. Selected aspects of Burrowing Owl ecology and behavior. Condor 75: 446–456.

McClure, H. E. 1984. Bird banding. The Boxwood Press, Pacific Grove, CA.

Mead, R. 1974. A test for spatial pattern at several scales using data from a grid of contiguous quadrats. Biometrics 30:295-307.

Moran, P. 1950. Notes on continuous stochastic phenomena. Biometrika 37:17-23.

Moulton, C.E., R.S. Brady, and J.R. Relthoff. 2004. Territory defense of nesting burrowing owls: responses to simulated conspecific intrusion. Journal of Field Ornithology 75:288-295.

New Mexico Department of Game and Fish. 2007. Burrowing owl survey and mitigation methods and mitigation if they are found. New Mexico Department of Game and Fish, Albuquerque.

NRCS and NSS. Undated Current Issue. Keys to Soil Taxonomy, Title 430-VI. U.S. Department of Agriculture Natural Resources Conservation Service and National Soil Survey.

NRCS. 1993. Soil survey manual. Agricultural Handbook 18, United States Department of Agriculture. Prepared by the Soil Survey Division Staff; available online at: http://soils.usda.gov/technical/manual

NRCS. 1995. Soil Taxonomy. Agricultural Handbook 436, U.S. Department of Agriculture, Natural Resources Conservation Service.

NRCS. 2005. Soil survey geographic (SSURGO) database for Imperial County, California, Imperial Valley Area. Soils Data Mart. United States Department of Agriculture,

Natural Resources Conservation Service. Available online at: http://soildatamart.nrcs.usda.gov

Orians, G.H., and N.E. Pearson. 1979. On the theory of central place foraging, p. 155-177. *In* D.H. Horn, R. Mitchell, and G.R. Stairs [eds.]. Analysis of ecological systems. Ohio State University Press, Columbus.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs 62.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs 62:1-136.

Peterman, R.M. 1990. The importance of reporting statistical power: the forest decline and acidic deposition example. Ecology 71(5):2024-2027.

Petersen, C. G. J. 1896. The yearly immigration of young plaice into the Limfjord from the German Sea. Report of the Danish Biological Station 1895 6:1-77.

Petitt, E. and N. Valiere. 2006. Estimating population size with noninvasive capture-mark-recapture data. Conservation Biology 20:1062-1073.

Plumpton, D. L., and R. S. Lutz. 1993. Influence of vehicular traffic on time budgets of nesting burrowing owls. Journal of Wildlife Management 57:612–616.

Pollock, K. H., J. D. Nichols, C. Brownie, and J. E. Hines. 1990. Statistical inference for capture–recapture experiments. Wildlife Monographs 107:1-97.

Rangel, T. F. L. V. B., J. A. F. Diniz-Filho, and L. M. Bini. 2006. Towards an integrated computational tool for spatial analysis in macroecology and biogeography. Global Ecology and Biogeography 15:321-327.

Ratcliff, B. D. 1986. The Manitoba burrowing owl survey 1982-1984. Blue Jay 44:31-37.

Remsen, J.V., Jr. 1978. Bird species of special concern in California. California Department of Fish and Game, Wildlife Management Branch Administraive Report, No. 78-1. Sacramento, California, USA.

Ribeiro, P. J. J., O. F. Christensen, and P. J. Diggle. 2003. Geostatistical software - geoR and geoRglm. DSC 2003 Working Papers: http://www.ci.tuwien.ac.at/Conferences/DSC-2003/.

Rich, T. 1986. Habitat and nest-site selection by Burrowing Owls in the sagebrush steppe of Idaho. Journal of Wildlife Management 50:548-555.

Rosenberg, K. K., and K. L. Haley. 2004. The ecology of Burrowing Owls in the Agroecosystem of the Imperial Valley, California. Studies in Avian Biology 27:120-135.

Rosenberg, K. K., and K. L. Haley. 2004. The ecology of Burrowing Owls in the Agroecosystem of the Imperial Valley, California. Studies in Avian Biology 27:120-135.

Royle, J. A. 2004. *N*-mixture models for estimating population size from spatially replicated counts. Biometrics 60:108-115.

Royle, J. A., and J. D. Nichols. 2003. Estimating abundance from repeated presence-absence data or point counts. Ecology 84:777-790.

Schoener, T.W. 1979. Generality of the size-distance relation in models of optimal feeding. American Naturalist. 114:902-914.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters. Second edition. Charles Griffin, New York, New York, USA.

Sheffield, S. R. 1997. Current status, distribution, and conservation of the burrowing owl (Speotyto cunicularia) in midwestern and western North America. Pages 399–407 in J. R. Duncan, D. H. Johnson, and T. H. Nicholls, editors. Biology and conservation of owls of the Northern Hemisphere, second international symposium. U.S. Forest Service General Technical Report NC-GTR-190, North Central Forest Experiment Station, St. Paul, Minnesota, USA.

Shyry, D. T., T. I. Wellicome, J. K. Schmutz, G. L. Erickson, D. L. Scobie, R. F. Russell, and R. G. Martin. 2001. Burrowing owl population-trend surveys in southern Alberta: 1991–2000. Journal of Raptor Research 35:310–315.

Sibly, R. M., J. Hone, and T. H. Clutton-Brock, eds. 2003. Wildlife population growth rates. Cambridge University Press, New York, New York, USA.

Steel, R. G. D., J. M. Torrie, and D. A. Dickey. 1997. Principles and procedures of statistics: a biometrical approach. McGraw-Hill Companies, Inc., New York, USA.

Steenhof, K. and M. N. Kochert. 1982. An evaluation of methods used to estimate raptor nesting success. Journal of Wildlife Management 46:885-893.

Steidl, J. S., J. P. Hayes, and E. Schauber. 1997. Statistical power analysis in wildlife research. Journal of Wildlife Management 61:270–279.

Steidl, R. J. 1995. Human impacts on the ecology of bald eagles in interior Alaska. Dissertation. Oregon State University, Corvallis, Oregon, USA

Steidl, R. J. and L. Thomas. 2001. Power analysis and experimental design. Pages 14-36 In Scheiner, S. M. and J. Gurevitch (eds). Design and analysis of ecological experiments, 2nd ed. Oxford University Press, New York.

Taylor, B. L. and T. Gerrodette. 1993. The uses of statistical power in conservation biology: the vaquita and northern spotted owl. Conservation Biology 7:489-500.

Thomsen, L. 1971. Behavior and ecology of burrowing owls on the Oakland Municipal Airport. The Condor 73:177-192.

Tobin, P. C. 2004. Estimation of the spatial autocorrelation function: consequences of sampling dynamic populations in space and time. Ecography 27:767-775.

Turner, M., R. O'Neill, R. Gardner, and B. Milne. 1989. Effects of changing spatial scale on the analysis of landscape pattern. Landscape Ecology 3:153-162.

U.S. Fish and Wildlife Service. 2002. Birds of conservation concern. U.S. Department of the Interior Fish and Wildlife Service, Administrative Report, Arlington, Virginia, USA. ,http://migratorybirds.fws.gov/reports/bcc2002.pdf. Accessed 18 July 2007.

Wedgewood, J. A. 1978. The status of the burrowing owl in Canada. A report prepared for the Committee on the Status of Wildlife in Canada. Canadian Wildlife Service, Ottawa.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46 Supplement:120–138.

White, G. C., D. R. Anderson, K. P. Burnham, and D. L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory Rep. LA-8787-NERP, Los Alamos, New Mexico, USA.

Wiens, J. 1989. Spatial scaling in ecology. Functional Ecology 3:385-397.

Williams, B. K., J. D. Nichols, and M. J. Conroy. 2002. Analysis and management of animal populations. Academic Press, San Francisco, California, USA

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70:164-168

Zarn, M. 1974. Burrowing owl (*Speotyto cunicularia hypugaea*). Habitat management for unique or endangered species. U.S. Bureau of Land Management, Denver, Colorado. Report No. 11, Technical Note T-N-250.

APPENDICES

Appendix I

FIELD BIOLOGISTS

Name	Position	Name	Position
Aaron M. Viducich	Field biologist	Julia Harnad	Field biologist
Alexa DeJoannis	Field biologist	Kara Butler	Field biologist
Amy Musante	Field biologist	Kate Dalley	Field biologist
Andrew Davenport	Field biologist	Katie Kauffman	Field biologist
Andrew Stephens	Field biologist	Kevin Dickinson	Field biologist
Anne Bloomfield	Field biologist	Kevin O'Brian	Field biologist
Ashley C. Persinger	Field biologist	Laurel Anne Ferreira	Field biologist
Beth Dirksen	Field biologist	Laurel Genzoli	Field biologist
Bill Trione	Field biologist	Lauren MacFarland	Field biologist
Carla Mingione	Field biologist	Leah Kenney	Field biologist
Caroline Poli	Field biologist	Malcolm Grant	Field biologist
Cassidy Gratten	Field biologist	Malia Volke	Field biologist
Cassie Waters	Field biologist	Matthew Dresser	Field biologist
Chris Chutter	Field biologist	Melinda Conners	Field biologist
Craig Moran	Field biologist	Michele Kuter	Field biologist
Dan Burnett	Field biologist	Nate Richardson	Field biologist
Daniel G. Burnett	Field biologist	Pierre J. Goulet	Field biologist
Dave Bittner	Field biologist	Robb S. A. Kaler	Field biologist
Deborah Sharpe	Field biologist	Robert C. Fowler	Field biologist
Elias A Elias	Field biologist	Samantha Burrell	Field biologist
Elizabeth Donadio	Field biologist	Sarah Malick	Field biologist
Emily Kackorek	Field biologist	Sarah Sells	Field biologist
Gabrielle Gareau	Field biologist	Sean Row	Field biologist
Gabrielle Robinson	Field biologist	Shawn Carroll	Field biologist
Greg Levandoski	Field biologist	Shelly Vogel	Field biologist
Inger Marie Laursen	Field biologist	Sherri Kies	Field biologist
Jacob Cowan	Field biologist	Steve Borrego	Field biologist
James M. Field	Field biologist	Steve Tucker	Field biologist
Jeff Lincer	Field biologist	Tara Eisenhower	Field biologist
Jim Luttrell	Field biologist	Valerie Eurs	Field biologist
John Konecny	Field biologist	Whitney Menu	Field biologist
John Warzybok	Field biologist	William R. Trione	Field biologist
Julee Shamhart	Field biologist	Zachary Wallace	Field biologist

Appendix II

ACCURACY OF POINT LOCATIONS AS LOCATIONS OF BURROWING OWLS

JEFFREY A. MANNING

INTRODUCTION

Closed-population methods provide a powerful tool to obtain accurate estimates of annual Burrowing Owl population sizes in the HCP. These methods require that every newly captured animal is uniquely 'marked,' recaptured animals are recorded as 'recaptures,' and sampling be completed in a brief period to ensure the population is closed during sampling (White et al. 1982). However, capturing, handling, marking, and recapturing animals is labor intensive, thus making these methods difficult to accomplish for studies of large populations across vast areas. Because the HCP encompasses the vast agricultural matrix of the Imperial Valley, and is anticipated to support an estimated 5,600 pairs of breeding Burrowing Owls, and as many as 7,795 (Desante et al. 2004), we developed the point-coordinate capture-recapture method (presented in Chapter 5) to allow surveys to be accomplished in a timely manner in order minimize violations of the assumptions associated with close-population theory.

The point-coordinate capture-recapture technique relies on owl locations (coordinates) as 'marks' and 'recaptures.' Each time an owl was observed, its coordinates were recorded. The first time a coordinate was recorded during visual surveys, it was considered the first mark of an individual Burrowing Owl, and subsequent coordinates were considered recaptures. This novel approach to mark-recapture sampling minimizes time spent marking and recapturing individuals, thus making it a cost effective method for sampling the large population of Burrowing Owls across the HCP. It also eliminates behavioral responses elicited by using bait and/or capturing and handling (Otis et al. 1978, White et al. 1982). However, using this technique leads to sources of measurement error described in Chapter 5. To minimize the intrusion of field measurement error into the analytical and sampling errors (which scale up to the overall error that bounds a population estimate), it is important to record accurate field measurements of owl locations.

Here, I assessed the accuracy of our field equipment and method of recording point coordinate locations. My objective was to assess the accuracy of our methods to ensure that they met the 3-m accuracy we proposed in our original proposal and complied with Section 4.5.2.2 of the HCP, which specified that owl territories were to be recorded ≤30m.

METHODS

I followed the field protocols used to record owl locations in Chapter 7. Those methods included obtaining a hand-held global positioning system (GPS) location of where observers stood, and using compass directionality, and range finder distance to estimate

the coordinates of each individual or pair of owl(s) observed. Because we anticipated that numerous field crews would be required to conduct surveys each year, I arranged for 10 different biologists to collect the data. The biologists:

1. used a Trimble GeoExplorer XM GPS with ±1m accuracy and with the GPS slider set halfway to balance productivity with precision and postprocessed differential correction to acquire GPS coordinates at 105 randomly selected locations across the HCP (Figure II.1). These were considered as 'known' points,
2. randomly selected ≥5 positions/known point at various distances (<140m) from the known points (totaling 630 positions), and
3. used a Trimble GeoExplorer XM, Suunto Handheld Directional Compass, and Opti-Logic Laser Rangefinder with ±1m accuracy to compute new coordinates that estimated each 'known' location from the random points where observers stood.

I used the distance between known and estimated locations as the dependent variable and the distance (the observer was) from the known location as the independent variable in a simple linear regression model. I considered distance between estimated and known points as an index of accuracy, where shorter distances reflected higher accuracy. I used the resulting linear model equation to predict the maximum distance an observer can be from an owl when measuring/recording owl locations to attain an average error of 3 m.

Results

1. Distances from the known point that were sampled ranged from 0.12-15.2 meters from known point (Figure II.1).
2. The observer distance from a known point when the distance between the estimated and known points was the required maximum (3 m) was 36.3 m (3/0.0826) (Figure II.2).
3. Distances <36.3m produced estimated locations with average errors <3 m (Figure II.2).

CONCLUSIONS AND RECOMMENDATIONS

My results showed that hand-held GPS locations, compass directions, and range finder distances are suitable for estimating locations of objects like Burrowing Owls with reasonable accuracy. With increased distance between observers and known points, estimated distances were less accurate (i.e., farther from known points). These field methods are sufficient for use in producing average estimated coordinates ≤3 m of Burrowing Owls or their nests as long as observers are ≤36.3 m from their target.

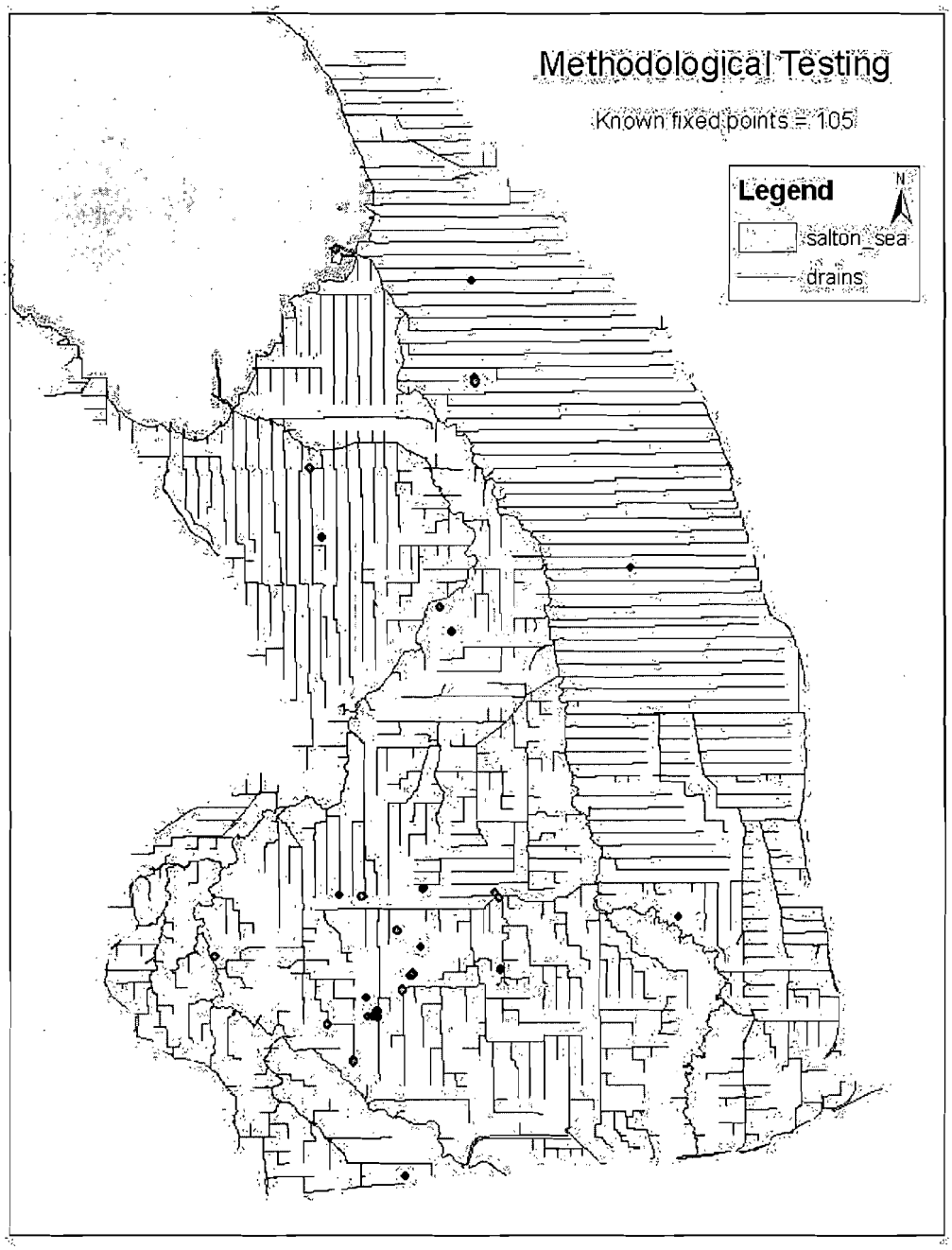


Figure II.1. Locations of known fixed points used to test the accuracy of field sampling techniques to estimate Burrowing Owl locations (derived from a combination of GPS, range finder, and directional compass) in the HCP Study Area, Imperial County, California, April 16-May 20, 2006.

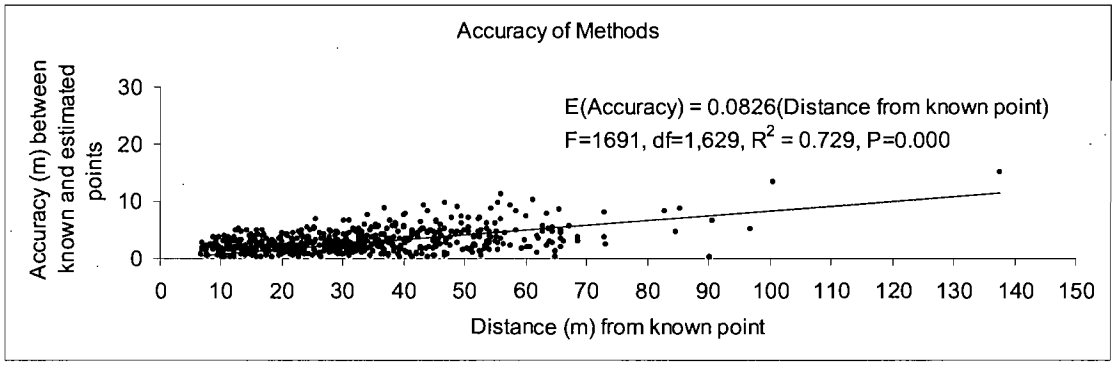


Figure II.2. Distance between estimated and known points as a function of observer's distance from a known point in the HCP, Imperial County, California.

LITERATURE CITED

Desante, D. F., E. D. Ruhlen, and D. K. Rosenberg. 2004. Density and abundance of burrowing owls in the agricultural matrix of the Imperial Valley, California. Studies in Avian Biology 27:116-119.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs 62.

White, G. C., D. R. Anderson, K. P. Burnham, and D. L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory Rep. LA-8787-NERP, Los Alamos, New Mexico, USA.

Appendix III

REMOTE CLASSIFICATION OF CROP AND LAND COVER TYPES

JEFFREY A. MANNING AND MIKE FALKOWSKI

INTRODUCTION

Burrowing owls have been reported to use specific types of crops in Imperial County, California (Rosenberg and Haley 2004). Knowledge of relationships between owl abundance and specific types of crops would be helpful in developing survey protocols for burrowing owls in this region, but such knowledge is dependent on availability of crop and owl data. Owls were surveyed across the Imperial Irrigation District's (IID) right-of-ways in the spring of 2007, but data (in a usable format) on when, where, and what types of crops are present are currently unavailable. This is due to the large extent of the Imperial Valley and high number of property owners, diversity of crops, and frequency of crop rotation. In particular, the large extent and numerous landowners pose challenges for mapping crops during brief periods (i.e., spring). Furthermore, in order to test hypotheses regarding relationships between owl abundance and crops, a spatial, time series dataset of crops is required, and such data are complex and impractical to attain from ground surveys. We evaluated the efficacy of satellite remote sensing for large-area crop type classification in the IID's Habitat Conservation Planning (HCP) Area and mapping crop assemblages and individual crop types with the intent that these data may be suitable for assessing relationships between owls and crops.

For the past 20 years, satellite remote sensing has been used to map, inventory, and monitor land cover types (*e.g.*, Haack 1987, Vogelman *et al.* 2001, Falkowski *et al.* 2006), including agricultural crops (Bauer 1985, Ortiz *et al.* 1997). Remotely sensed data acquired by space-borne sensors are ideal for gathering, mapping, and monitoring information on land surface and vegetation characteristics across large regions such as the agricultural matrix comprising the HCP. The Landsat family of sensors was designed specifically with such information needs in mind (Beck and Gessler, In Press).

There are numerous benefits to using satellite remote sensing data for such a task. For instance, remotely sensed data provide a time-efficient approach for mapping crops because it can be automatically processed in a timely manner. Landsat imagery can produce maps measuring a variety of landscape features like land cover and crop type. Compared to traditional field-based mapping techniques, maps produced via remotely sensed data require a relatively small amount of field data, resulting in reduced sampling effort. Lastly, it provides complete coverage across large areas as well as a long-term data archive.

Methods of using Landsat imagery to classify landscape features and vegetation continue to evolve, leading to increased accuracy. For example, individual crop types have been successfully classified from single date Landsat imagery. But, recent studies found

increased accuracy through the incorporation of multi-date imagery (Oetter, *et al.* 2000). This is because different crops have unique phenologic trajectories (e.g., stages of development and growth patterns) that can be detected via a time series of remotely sensed data (Oetter, *et al.* 2000). Thus, multi-date imagery series would be a preferred approach to classifying crops across the HCP.

Another approach that can improve accuracy is object-based classification. Typically, remote sensing classifications are pixel-based, meaning that each pixel is classified as a specific type of land surface or vegetation independent of conditions in neighboring pixels. Because landsat image pixels are 30 x 30m, agricultural fields are comprised of numerous pixels. Variable crop conditions (e.g., stages of development) and soil types among pixels within a field leads to variation in the classification of pixels in a field. This variably is represented by a salt and pepper appearance in pixel-based classification maps (Figure 1A). This within-field variably can reduce accuracy of classifying fields correctly. A solution is to use fields as objects in an object-based classification, which quantitatively groups similar contiguous pixels (Figure 1B), thereby using within-field frequency distributions to classify individual agricultural fields. Object-based classifications have been successfully applied to other large-scale areas such as forested environments (Desclee *et al.* 2006). Because object-based techniques may improve the accuracy of classifying crops at the resolution of agricultural fields rather than pixels within fields (Desclee *et al.* 2006), this approach is preferred for the agricultural matrix comprising much of the HCP.

OBJECTIVES

The overall objective was to produce reasonably accurate maps of crop types intended for use in assessing relationships between owl abundance and crops and developing future burrowing owl population surveys. Specific objectives were to:

1. Incorporate a time series of Landsat data to classify vegetation and crops types each Spring from 2003 to 2007.

2. Assess the efficacy and accuracy of an object-based classification technique in the Imperial County agricultural environment.

3. Produce a GIS polygon layer of agricultural fields with attribute information specifying crop type in each polygon each spring from 2003 to 2007.

METHODS

Ground Reference Data Collection

Ground reference data were collected at 420 randomly located agricultural crop fields across the 500,000-acre HCP from March 31-April 22, 2007. At each random field, a point location was randomly selected, and the type and stage of development (bare ground, sprout, mid-stage, mature, abandoned, grazed, stubble) were visually identified

by a crop specialist and recorded at that point. Field data were recorded using a Trimble GeoXM GPS. Sample sizes for each crop type ranged from 3 to 52 (Table 6.1).

Landsat Image Acquisition and Processing

We acquired 3 Landsat images (30 x 30 m resolution) for each spring from 2003 to 2007 (totaling 15 images) from the United States Geological Survey (USGS). The image acquisition dates (Table 6.1) coincided with the collection of ground reference data.

We originally proposed to classify crops with Landsat 5 imagery. However, due to large amounts of cloud cover during March and April it was necessary to use a combination of Landsat 5 and Landsat 7 data to avoid contamination of the data by clouds (i.e., if a particular Landsat 5 image was contaminated by clouds, we used a cloud free Landsat 7 image acquired within a similar time frame). This strategy provided imagery coverage during the desired time frame for each of the 5 years between 2003 & 2007, inclusive.

Although there was a potential disadvantage of using Landsat 7 data for this study (e.g., the Landsat 7 sensor scan line corrector (SLC) failed on July 14th, 2003, resulting in the raw imagery having systematic gaps in the data (Figure 2a)), remedies were available. For example, the USGS has developed an interpolation methodology to fill in missing data values based upon neighboring scan lines (Figure 2b). Also, the SLC error is more pronounced toward the edges of a Landsat scene (USGS 2007), but since the Imperial Valley Region is approximately at the center of a Landsat scene, the interpolated products produce seamless data for the HCP. Lastly, the object-based classification approach implemented in this project (described below) should be relatively unaffected by any interpolated values within a Landsat 7 scene since the classification rules rely upon distributional statistics within each individual agricultural field. Therefore, we believe this Landsat processing approach is comparable, if not superior, to the originally proposed approach.

We systematically processed each image to correct for radiometric and geometric errors via a streamlined image processing methodology developed by Beck and Gessler (In Press). This was accomplished by geo-reregistering the April 2007 image to high-resolution digital orthophotos, acquired by the National Agriculture Imagery Program (NAIP), spanning the HCP. The remaining 14 Landsat images were then co-registered to the April 2007 image. This geo-registration process ensured that each Landsat scene had a geo-location accuracy of < 15 m on the ground.

Following geometric correction, each image was radiometrically calibrated and converted from raw digital number to percent reflectance via equations and coefficients developed by Markhan and Barker (1986), Chander and Markham (2003), and Williams (2004). This process removed radiometric errors and ensured that each image was directly comparable to another image within the time series, regardless of acquisition date and/or radiometric differences between the Landsat 5 and Landsat 7 sensors (*i.e.,* this process allows the direct comparison of Landsat 5 and Landsat 7 images). Following radiometric

calibration, we also removed atmospheric effects (*e.g.,* haze and dust) via the COST atmospheric correction model (Chavez 1996).

Creation of Image Objects for Object-based Classification

We initially proposed using a technique referred to as image segmentation to create a GIS polygon layer that would outline individual agricultural fields for an object-based classification. However, we later chose to use Common Land Units (CLUs; U.S. Department of Agriculture, Farm Service Agency, Aerial Photography Field Office, Salt Lake City, Utah; www.apfo.usda.gov) as objects. Each CLU represents an agricultural field. Thus, the CLU layer was intersected with each Landsat image to create groups of pixels representing image objects (hereafter referred to as agricultural fields).

Distributional statistics (*e.g.,* mean, standard deviation, range, minimum values and maximum value of pixels) were calculated for each Landsat band within each agricultural field. This process created a GIS layer containing the aforementioned distributional statistics for each agricultural field across the HCP for each of the 5 years in the Landsat time series (Figure 3). The resulting GIS layer contained approximately 7,000 individual polygons (representing agricultural fields within the HCP), each containing 35 different data attributes quantifying the distributional statistics of Landsat pixels within each agricultural field. Following this process, fields sampled during data collection were separated out of the 2007 GIS layer and used as training data in the classification, as described below.

Distributional statistics were also calculated for the Normalized Difference Vegetation Index (NDVI), which is sensitive to living plant biomass (Tucker 1979). These metrics provided an opportunity to improve our classification of individual crops in the HCP because individual crops display distinct variation in their spectral responses over time (phonologic trajectories; e.g. http://rst.gsfc.nasa.gov/Sect3/Sect3_1.html). For example, Sudan grass fields in our study area showed low mean NDVI values in late March, and these rise through April, corresponding to plant establishment and growth during this time period (Figure 4). Sugar beet fields displayed a decreasing trend in the mean NDVI, which is mostly likely related to a gradual senesce of this crop (Figure 4), and the NDVI for alfalfa fields remained relatively constant through the time series (Figure 4).

Image Classification

Crops were hierarchically classified as groups (Level II crops) and individual species (Level III crops, Table 6.2) and using the Breiman Cutler classification (BCC) algorithm (Breiman 2001), also known as randomForest. The BCC algorithm is a classification and regression tree (CART) technique that has achieved excellent results in classifying remotely sensed imagery (Lawrence et al. 2006). The BCC algorithm develops classification rules by growing numerous (> 1,000) classification trees from random subsets of training data, and randomly selects which predictor variables (e.g., percent reflectance) to use for each decision rule. The correct classifications, or predictions, are then determined by selecting the most common decision rule at each node within the

group of multiple trees (Breiman 2001, Prasad *et al.* 2006, Lawrence *et al.* 2006). As the algorithm runs, bootstrap error estimates are calculated with the training data not used in the random selection process. The algorithm produces precise, unbiased decision rules, and does not overfit the training data (Breiman 2001). Because the BCC's bootstrapped error estimates are very accurate, researchers have recommended that it is unnecessary to estimate error from an independent dataset (i.e., all ground reference data can be used to develop classification rules (Breiman 2001, Lawrence *et al.* 2006)).

Accuracy Assessment and Classification

We used 2 separate methods of applying the BCC algorithm to assess accuracy of the level III crop classification: 1) with all of the ground reference data and 2) with 25% of the ground reference data held back for an independent accuracy assessment. We performed these 2 methods of assessing accuracy/error because we originally proposed the latter approach, but later decided that the former approach may be more reliable (Breiman, 2001, Lawrence *et al.* 2006).

Preliminary results from the 2 methods of assessing error (BBC and 25% of the ground reference data held back for an independent reference assessment) were similar (Level III species-level classification error was 68.6 % and 69.05 % for reduced and full datasets, respectively). Based on these comparable results and the conclusions of Breiman (2001) and Lawrence *et al.* (2006), we used the full set of ground reference data and their associated classification rules developed by the BCC algorithm to classify all of the time series data in lieu of using the originally proposed method.

We also used kappa statistics (KHAT; Cohen, 1960) to determine if our classifications were significantly better than that expected by chance (i.e. a random result) (Congalton and Green 1999). Kappa statistics are the most commonly used method of assessing the classification of subjects into categorical groupings. The kappa coefficient is an index that compares the agreement against that which might be expected by chance. It is considered as the chance-corrected proportional agreement, and possible values range from +1 (perfect agreement) via 0 (no agreement above that expected by chance) to -1 (complete disagreement). In other words, it corrects for chance agreement and tells us how much of the possible agreement over and above chance each classification achieved. Generally, kappa values >0.75 are considered to have a high degree of agreement beyond chance, values <0.40 have a low degree of agreement, and values between 0.40 and 0.75 represent a fair to good level of agreement beyond chance alone.

Once accuracy was assessed, the results from the image classification were used to generate 5 separate GIS polygon layers of predicted crop types in agricultural fields present in the HCP from late March to early April in 2003, 2004, 2005, 2006, and 2007 (Appendix A).

Classification Assumptions

Retrospectively classifying agricultural crops prior to 2007 assumes that the types of crops cultivated in the Imperial Valley from 2003-2006 were not drastically different than the crops present in 2007. In addition any future classifications will only be valid if the types of crops in cultivation reaming consistent.

RESULTS

The level II crop classification had an overall accuracy of 84%, with the accuracy of bare ground = 66.76 %, grass crop = 81.41 %, and broad leaf/other crop = 88 % (Table 6.2). The level III classification, classified 31 individual crops, and had an overall accuracy of 69.05%, with individual class accuracies ranging from 0 % to 100 % (Table 6.2). There was a good degree of agreement beyond chance alone (kappa statistics = 0.71 and 0.67) for level II and level III classifications, respectively,

In the level III classification, five crops (artichoke, asparagus, cauliflower, cilantro, and parsley) were classified with 100% accuracy, four (alfalfa, sugar beets, watermelon, and triticale) were classified with 80-99% accuracy, and six others (corn, potato, radish, Bermuda grass, Sudan grass, and wheat) with 70-80%. Bell pepper, broccoli, carrot, kline grass, lettuce, mixed flowers all had class accuracies >50 %, while the cabbage, citrus, sugar cane, and wild oat classes each had accuracies of 0 %. Errors of omission and commission for the level II and level III classification are listed in Tables 6.3 and 6.4, respectively.

According to the level III classification, the total land area each crop occupied in the study area varied annually (Table 6.5). Alfalfa was the most common crop in cultivation, occupying about 45,000 – 70,000 ha of the HCP between March and April from 2003 to 2007. Sudan grass, Bermuda grass, and wheat also occupied large tracts of land between 2003 and 2007. Some of the least common crops in cultivation included potato, radish, bell pepper, and watermelon, among others.

DISCUSSION

The overall goal of this project was to use remotely sensed data to classify crop assemblages and individual crop types in order to assess their importance to burrowing owls across the HCP. We employed an object-based BCC classification algorithm to classify 31 different crop types with a 3-date time series of Landsat data (March – April), and achieved reasonably high accuracy, given the large number of crop categories classified.

Many of our level III individual crop categories had accuracies ≥75 %; and overall, our approach achieved accuracies equal to or higher than similar studies. For example, Akbari *et al.* (2006) classified Landsat imagery into 20 different crop categories and attained an accuracy of 62 %, while Belward and Hoyos (1986) classified Landsat imagery into 8 different crop categories and attained an overall accuracy of 64.8 %.

Lower numbers of crop categories can yield higher accuracies, as seen in our classification level II, but such groupings may not yield enough detail for relating crops to burrowing owl abundance in localized areas within the HCP. In fact, other studies have reported slightly higher accuracies (e.g., Janssen 1992 and Turker and Arikan 2004 attained 81 % accuracy), but this is likely due to classifying only 7 to 11 crop types, respectively. Given the relatively high number of crops classified in this study, which is important in order to assess their relative importance to burrowing owls, the accuracy is reasonably high.

The approximate 20% decline in overall accuracy between level II and III classifications was expected given the increased number of classes between the 2 categories. The GIS polygon layers produced by the level III classification predicted individual crop types with reasonable accuracy, given the 69.05% overall accuracy, and should be suitable for relating individual crops to burrowing owl abundance.

Of particular interest are the accuracies of bare ground (level II = 66.67%, level III = 41.17%) and grass crops (level II = 81.41%, level III: alfalfa=88.46%, Bermuda grass=70%, Sudan grass=76.09%, triticale=80%, and wheat=77.78%) because the results from one study suggest that owls may use bare ground more than other cover types near nests and hay crops more than other types at distances away from nests (Rosenberg and Haley 2004). The high levels of accuracy for those crops from these analyses should produce a dataset suitable for assessing their importance as correlates of owl abundance.

Table 6.1. Acquisition dates and sensor of Landsat data used.

Year	Acquisition Date	Sensor
2007	28-Mar	Landsat 5
	13-Apr	Landsat 5
	29-Apr	Landsat 5
2006	1-Mar	Landsat 7
	10-Apr	Landsat 5
	26-Apr	Landsat 5
2005	30-Mar	Landsat 7
	7-Apr	Landsat 5
	15-Apr	Landsat 7
2004	27-Mar	Landsat 7
	12-Apr	Landsat 7
	20-Apr	Landsat 5
2003	25-Mar	Landsat 7
	10-Apr	Landsat 7
	26-Apr	Landsat 7

Table 6.2. Crop classes and associated class accuracies. Overall accuracies for the level II and Level III classifications are 84 %and 69.05 %, respectively.

Level I	Level II	% Accuracy	Level III	Sample Size	% Accuracy
Agriculture	Broad Leaf Crops / Other	88.00	Alfalfa	52	88.46
			Artichoke	4	100.00
			Asparagus	4	100.00
			Bamboo	4	50.00
			Bell Pepper	5	40.00
			Broccoli	9	44.44
			Cabbage	4	0.00
			Cantaloupe	13	61.54
			Carrot	7	42.85
			Cauliflower	4	100.00
			Cilantro	4	100.00
			Citrius	3	0.00
			Corn	27	74.07
			Cotton	6	66.67
			Lettuce	7	42.85
			Mixed Flowers	4	25.00
			Onion	23	69.56
			Parsley	4	100.00
			Potato	4	75.00
			Radish	4	75.00
			Sugar Beets	33	93.94
			Sugar Cane	4	0.00
			Watermelon	5	80.00
	Grass Crops	81.41	Bermuda Grass	50	70.00
			Fox Tail Grass	3	0.00
			Kline Grass	11	36.36
			Sudan Grass	46	76.09
			Triticale	4	80.00
			Wheat	36	77.78
			Wild Oat	6	0.00
	Bare Ground / Fallow	66.67	Bare Soil	17	41.17
			Fallow Field	13	53.85

Table 6.3. Level II crop classes and associated errors of omission and commission

Level II	% Omission Error	% Commission Error
Broad Leaf Crops / Other	11.96	13.81
Grass Crops	18.59	15.33
Bare Ground / Fallow	33.33	35.48

Table 6.4. Level III crop classes and associated errors of omission and commission.

Level III	% Omission Error	% Commission Error
Alfalfa	11.54	25.81
Artichoke	0.00	20.00
Asparagus	0.00	0.00
Bamboo	50.00	0.00
Bell Pepper	60.00	0.00
Broccoli	55.56	55.56
Cabbage	100.00	100.00
Cantaloupe	38.46	38.46
Carrot	57.14	0.00
Cauliflower	0.00	20.00
Cilantro	0.00	0.00
Citrius	100.00	100.00
Corn	25.93	53.49
Cotton	33.33	33.33
Lettuce	57.14	25.00
Mixed Flowers	75.00	50.00
Onion	30.43	5.88
Parsley	0.00	20.00
Potato	25.00	0.00
Radish	25.00	0.00
Sugar Beets	6.06	24.39
Sugar Cane	100.00	100.00
Watermelon	20.00	0.00
Bermuda Grass	30.00	30.00
Fox Tail Grass	100.00	100.00
Kline Grass	63.64	20.00
Sudan Grass	23.91	36.36
Triticale	25.00	0.00
Wheat	22.22	20.00
Wild Oat	100.00	100.00
Bare Soil	58.82	58.82
Fallow Field	46.15	50.00

Table 6.5. Total area (hectares) in Level III crops on a yearly basis.

Level III	2007	2006	2005	2004	2003
Alfalfa	54019.28	45084.26	58967.96	61656.46	70045.57
Artichoke	836.39	3860.93	410.76	955.77	1445.97
Asparagus	80.79	3.52	19.42	32.30	18.79
Bamboo	174.04	59.95	172.40	100.87	19.50
Bell Pepper	32.73	0.00	0.00	1.58	2.77
Broccoli	588.93	1039.94	576.68	667.59	504.58
Cabbage	112.66	105.76	63.13	8.04	112.34
Cantaloupe	3131.67	1422.76	4333.37	1677.43	2753.94
Carrot	1305.15	2397.77	1394.95	2147.18	1745.02
Cauliflower	104.68	5.97	14.57	7.71	14.55
Cilantro	53.12	18.92	170.37	167.58	258.25
Citrius	242.05	107.96	107.65	0.00	160.61
Corn	7793.99	12033.17	10736.31	7733.00	7830.95
Cotton	602.29	23.52	766.88	30.99	76.15
Lettuce	1092.11	1634.90	402.66	559.38	295.38
Mixed Flowers	24.78	0.00	23.07	3.82	17.66
Onion	4642.11	4548.52	4997.87	5777.00	6228.10
Parsley	133.09	88.25	99.96	177.46	4.67
Potato	23.09	14.32	0.00	0.00	0.00
Radish	43.27	0.00	1.21	2.62	0.00
Sugar Beets	9449.51	9061.19	10272.95	16770.93	13345.18
Sugar Cane	116.91	200.53	238.36	226.13	69.67
Watermelon	80.33	0.00	0.00	108.93	109.25
Bermuda Grass	30153.54	22318.60	29766.65	24178.47	17775.63
Sudan Grass	20608.22	41135.88	11646.85	18126.97	13928.84
Kline Grass	2940.99	848.37	269.93	1662.74	1188.23
Triticale	226.40	30.58	0.00	9.34	0.00
Wheat	18508.90	12096.07	16877.82	18142.11	25131.63
Wild Oat	1600.12	647.29	167.54	51.73	572.46
Bare Soil	9281.53	6470.37	19233.90	8089.26	5743.65
Fallow Field	11505.73	14305.72	7853.73	10491.60	10165.68

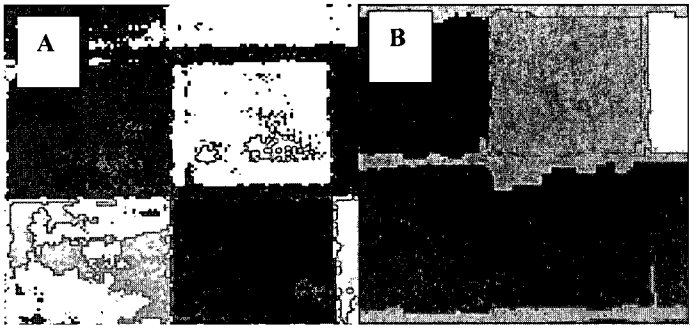


Figure 1. Pixel-based (A) and object-based (B) classifications

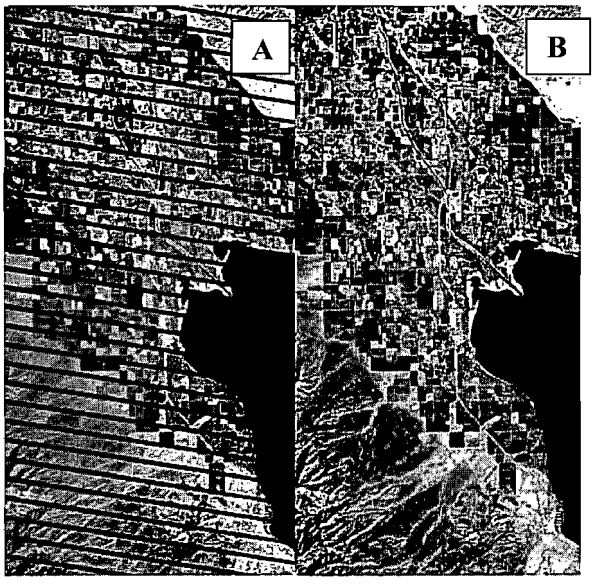


Figure 2. Landsat 7 Image with SLC error uncorrected (A) and corrected via interpolation (B). Image courtesy of the U.S. Geological Survey.

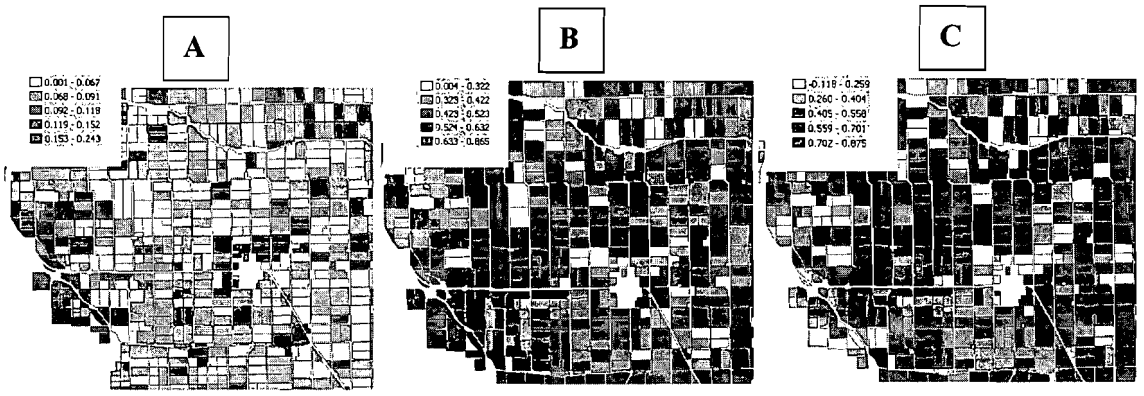


Figure 3. Distributional statistic GIS layer color coded by the mean (A), maximum (B) and standard deviation (C) of a single Landsat band.

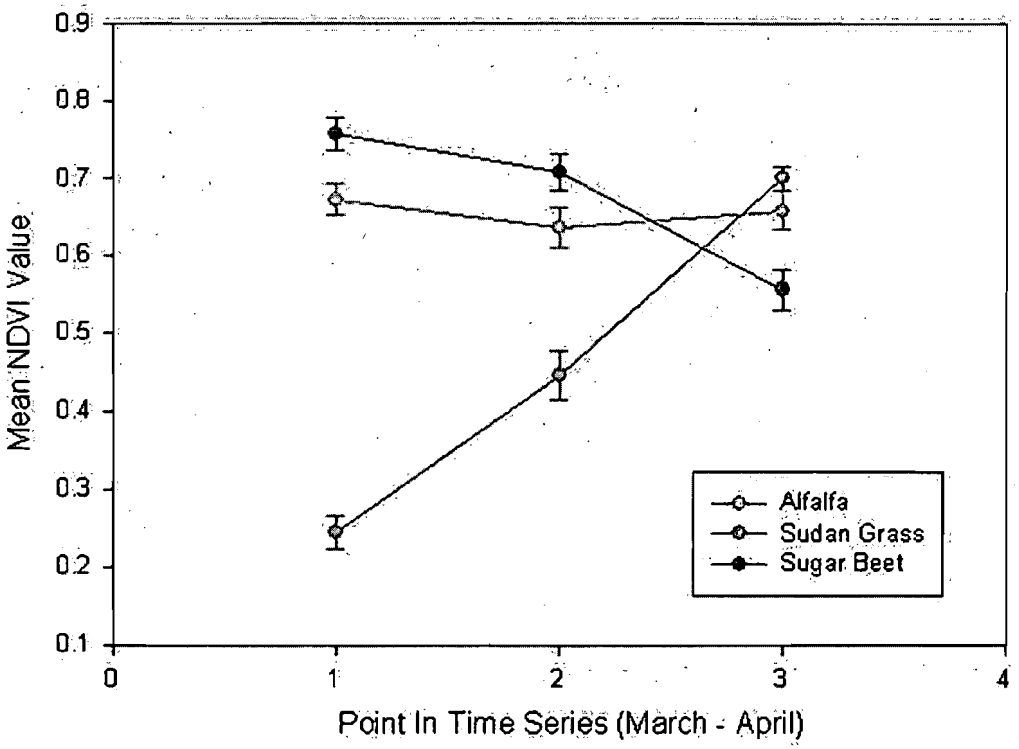
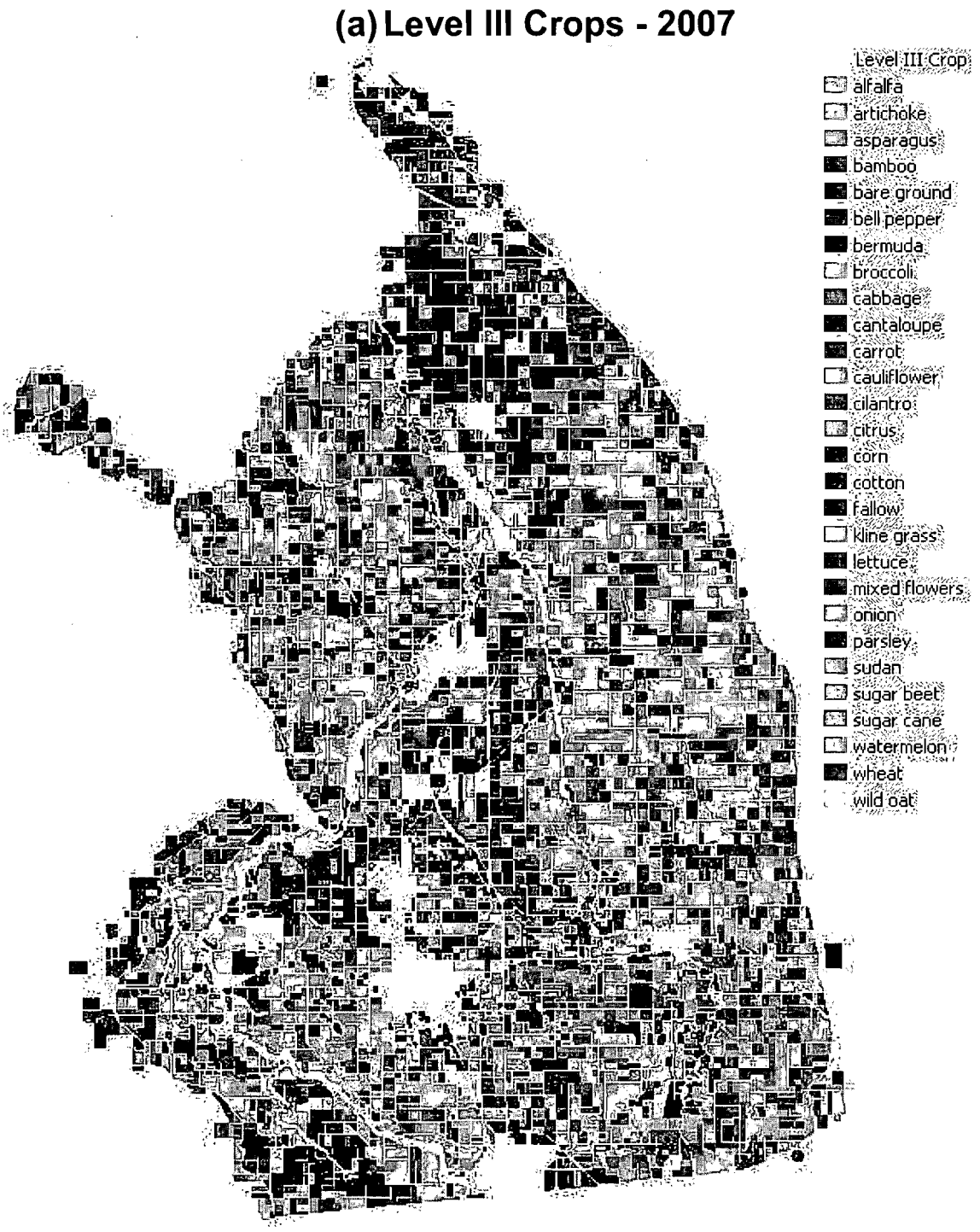
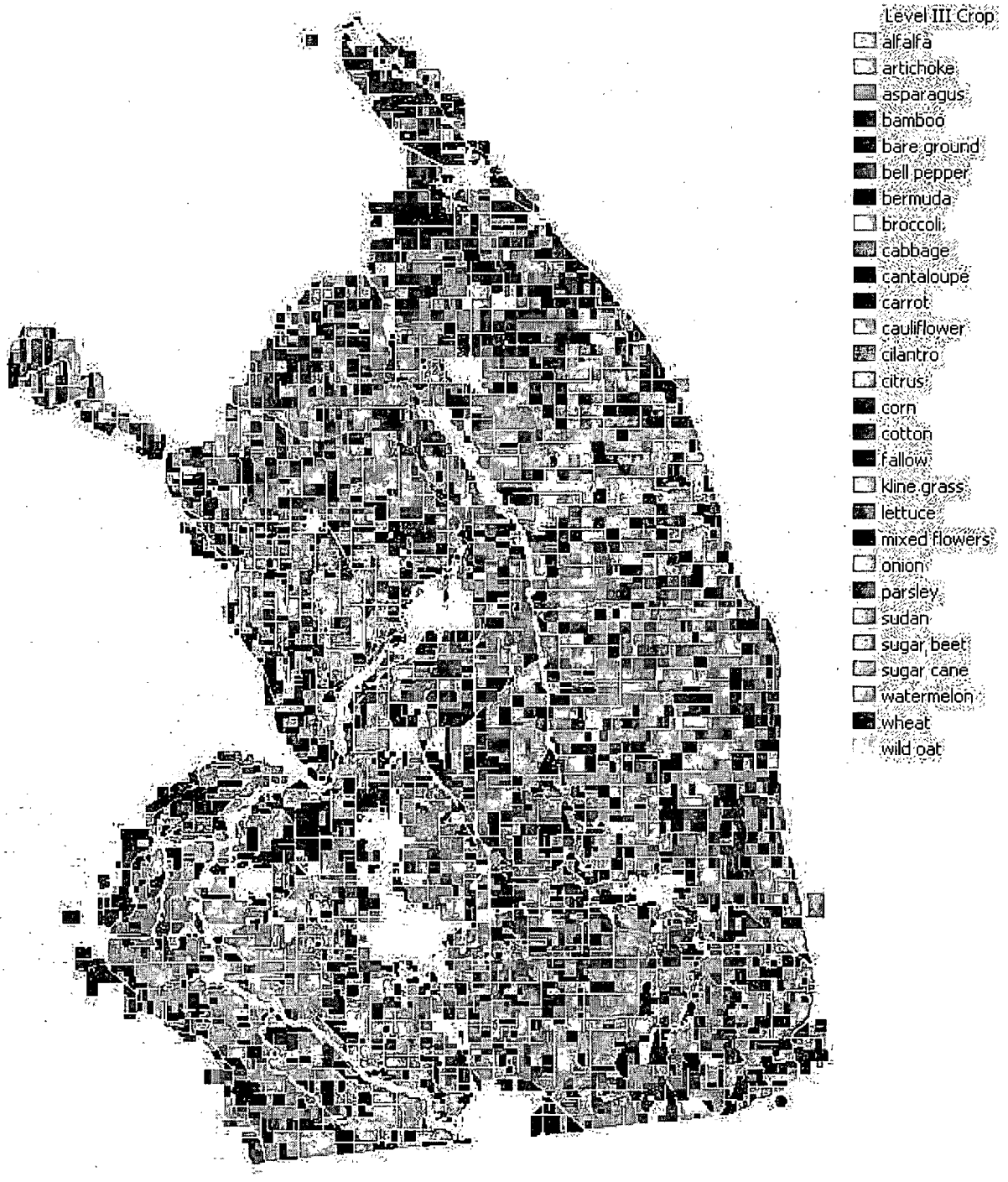


Figure 4. Phenologic trajectories for three selected crops.

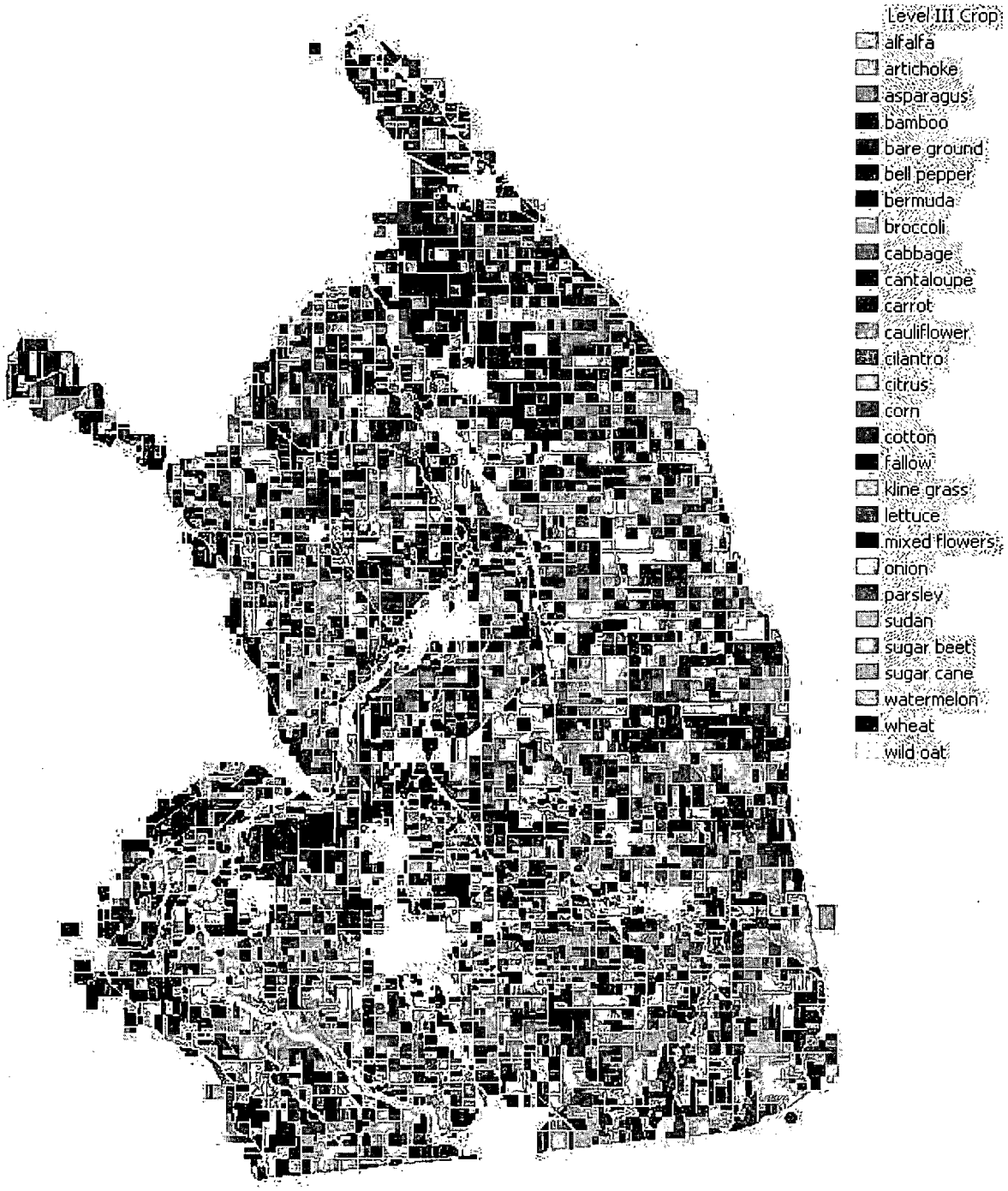
APPENDIX A

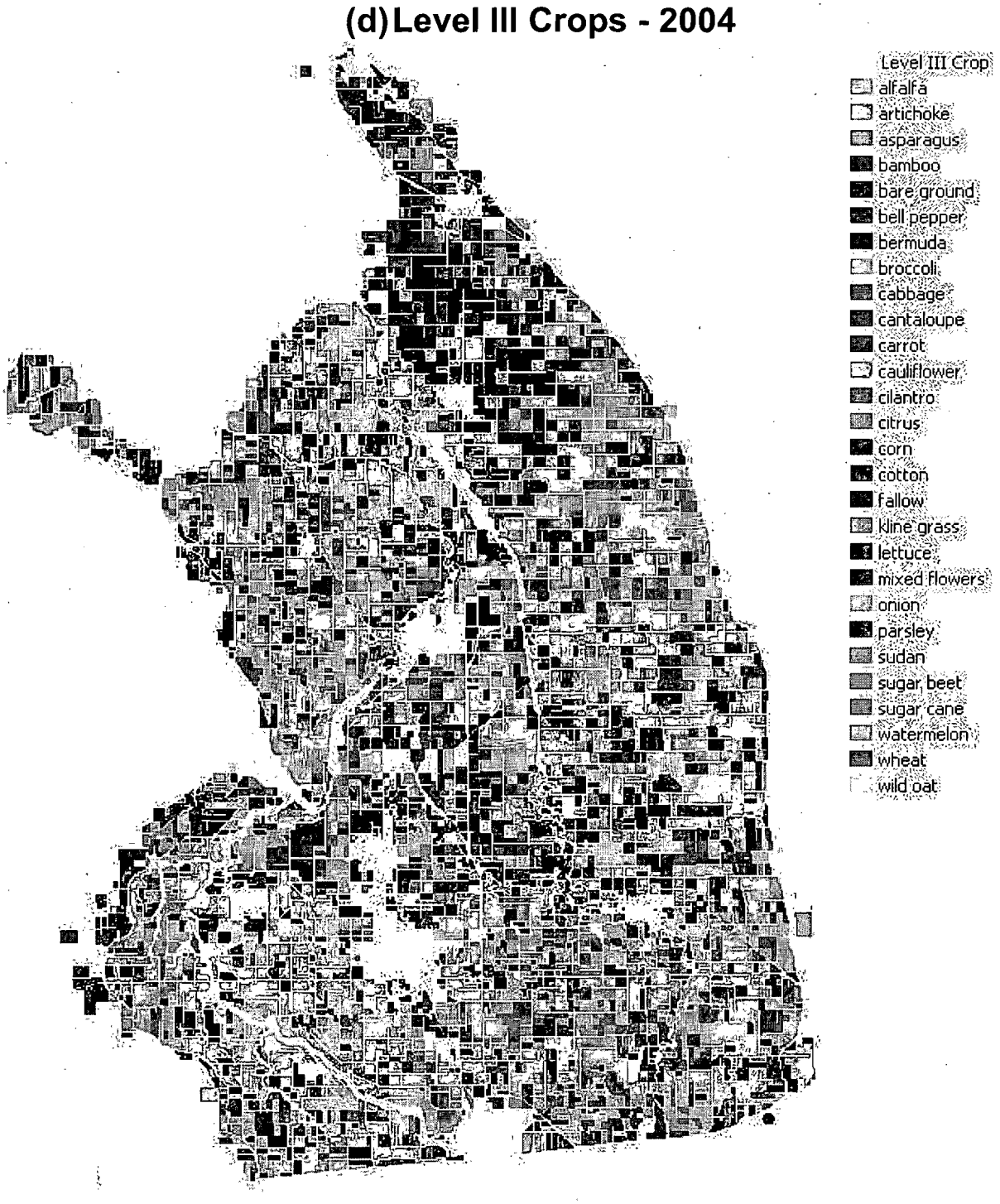

(a) Level III Crops - 2007
Level III Crop
alfalfa
artichoke
asparagus
bamboo
bare ground
bell pepper
bermuda
broccoli
cabbage
cantaloupe
carrot
cauliflower
cilantro
citrus
corn
cotton
fallow
kline grass
lettuce
mixed flowers
onion
parsley
sudan
sugar beet
sugar cane
watermelon
wheat
wild oat

(b) Level III Crops - 2006

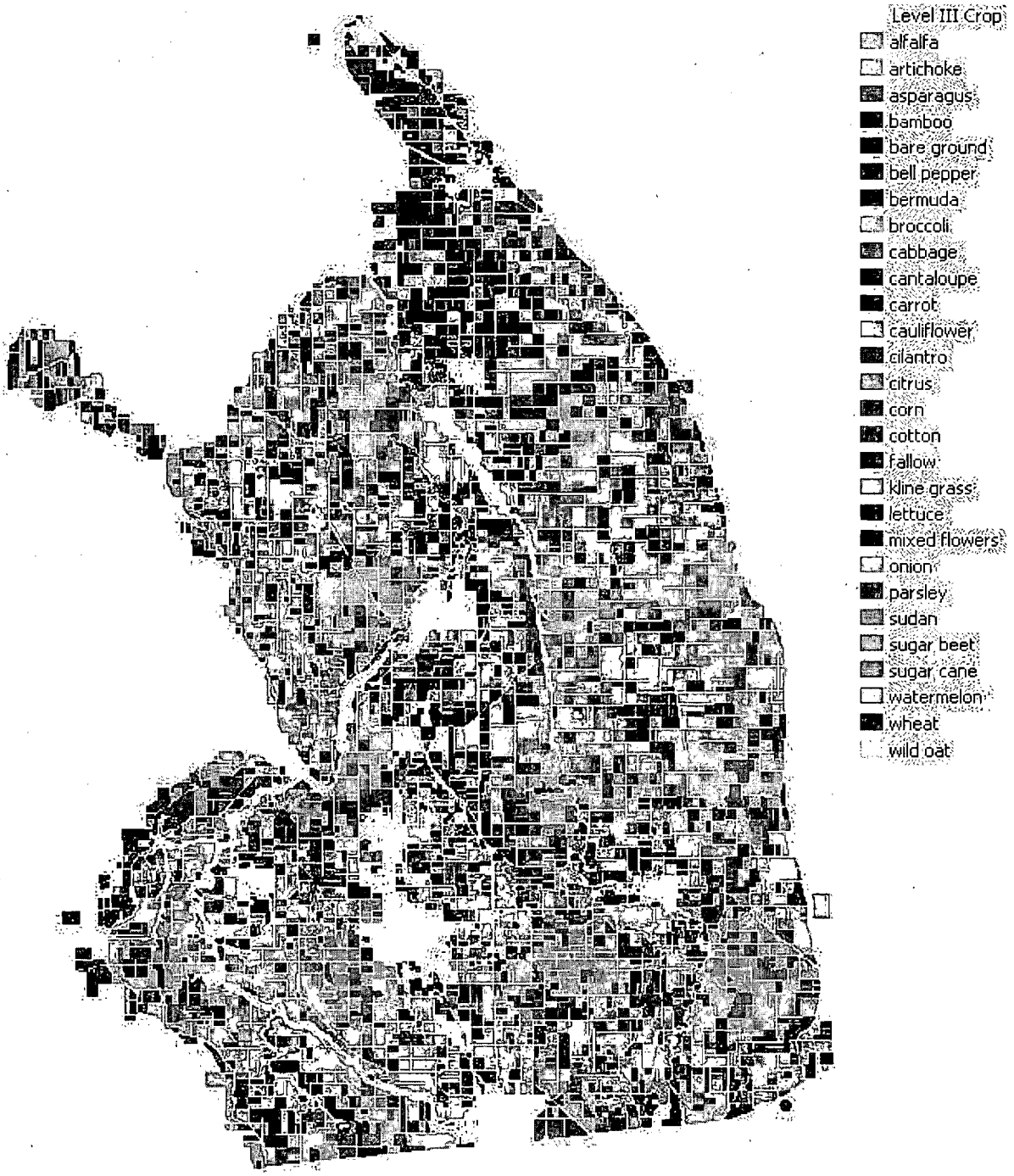


(c) Level III Crops - 2005




(d) Level III Crops - 2004
Level III Crop
alfalfa
artichoke
asparagus
bamboo
bare ground
bell pepper
bermuda
broccoli
cabbage
cantaloupe
carrot
cauliflower
cilantro
citrus
corn
cotton
fallow
kline grass
lettuce
mixed flowers
onion
parsley
sudan
sugar beet
sugar cane
watermelon
wheat
wild oat

(e) Level III Crops - 2003



LITERATURE CITED

Akbari, M., A. Mamanpoush, A. Gieske, M. Miranzadeh, M. Torabi, and H.R. Salemi. 2006. Crop and landcover classification in Iran using Landsat 7 imagery. International Journal of remote Sensing 27:4117-4135.

Bauer, M.E. 1985. Spectral inputs to crop identification and condition assessment. Proceedings of the IEEE 73:1071-1085

Beck, R., and P.E. Gessler. In Press. Development of a Landsat Time-Series for the Inland Northwest and an Application in Forest Status Assessment. Western Journal of Applied Forestry.

Belward, A.S. and A. de Hoyos. 1987. A comparison of supervised maximum likelihood and decision tree classification for crop cover estimation from multitemporal LANDSAT MSS data. International Journal of Remote Sensing 8:229-235.

Breiman, L., 2001. Random Forests, *Machine Learning* 45:5–32

Chavez, P.S., jr. 1996. Image-based atmospheric corrections - Revisited and Improved. Photogrammetric Engineering and Remote Sensing 62:1025-1036.

Chander, G, and B. Mrrkham. 2003. Revised Landsat-5 TM radiometric calibration procedure and postcalibration dynamic ranges. IEEE Transaction on Geosciences and Remote Sensing 41:2647-2677.

Cohen, J., 1960. A coefficient of agreement for nominal scales. Educational and Psychological Measures. 20:37–40.

Congalton, R.G. and K. Green... 1999. Assessing the Accuracy of Remotely Sensed Data. Lewis Publishers, New York, pp. 1–137.

Desclee, B., P. Bogaert, and P. Defourny. 2006. Forest change detection by statistical object-based method. Remote Sensing of Environment 102:1-11.

Falkowski, M.J., P.E. Gessler, P. Morgan, A.T. Hudak, and A.M.S. Smith. 2005. Characterizing and mapping forest fire fuels using ASTER imagery and gradient modeling. Forest Ecology and Management 217:129–146.

Haack, B. 1987. An assessment of Landsat MSS and TM data for urban and near-urban land-cover digital classification Source. Remote Sensing of Environment 21:201–213.

Janssen, L.L.F. and H. Middelkoop. 1992. Knowledge based crop classification of a Landsat Thematic Mapper image. International Journal of Remote Sensing 13:2872-2837.

Lawrence, R.L., S.D. Wood, and R.L. Sheley. 2006. Mapping invasive plants using hyperspectral imagery and Breiman Cutler classifications (RandomForest). *Remote Sensing of Environment,* 100. Pages 356-362 in M.J. Ortiz, A.R. Formaggio, and J.C.N. Epiphanio. 1997. Classification of croplands through integration of remote sensing, GIS, and historical database. International Journal of Remote Sensing 18:95-105.

Markham, B.L. and J.L. Barker. 1986. Landsat MSS and TM post-calibration dynamic ranges, exoatmospheric reflectances and at-satellite temperatures. EOSAT Technical Notes, August 1986.

Oetter, D.R., W.B. Cohen, M. Berterretche, T.K., Maiersperger, and R.E. Kennedy. 2000. Land cover mapping in an agricultural setting using multiseasonal Thematic Mapper data. Remote Sensing of Environment 76:139-155.

Rosenberg, D.K. and K.L. Haley. 2004. The ecology of burrowing owls in the agroecosystem of the Imperial Valley, California. Studies in Avian Biology 27:120-135.

Tucker, C.J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of the Environment 8:127-150.

Turker, M. and M. Arikan. 2004. Field-based crop mapping through sequential masking classification of multi-temporal Landsat 7 ETM images in Karacabey, Turkey. Proceedings of the 20th ISPRS congress, Istanbul, Turkey.

USGS, 2007 <http://landsat.usgs.gov/project_facts/project_news/2003.php> last accessed July 12th 2007.

Vogelman, J.E., S.M. Howard, L. Yang, C.R. Larson, B.K. Wylie, N. Van Driel. 2001. Completion of the 1990s National Land Cover Data set for the conterminous United States for Landsat Thematic Mapper data and ancillary data sources. Photogrammetric Engineering and Remote Sensing 67:650-655.

Williams, D. 2004. Landsat-7 Science Data User's Handbook, Acquired from http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_toc.html, NASA

Appendix IV

INCIDENTAL OBSERVATIONS OF DEAD BURROWING OWLS IN 2006, 2007, AND 2008

JEFFREY A. MANNING

INTRODUCTION

Incidental observations recorded during a population census can prove to be valuable for elucidating general patterns that can facilitate wildlife management, conservation, and research objectives. The locations of incidentally observed dead animals may be valuable in helping direct future studies of cause-specific mortality to particular areas where mortality is known to occur and be readily recordable. The standardized survey effort used to conduct the extensive Burrowing Owl population censuses in the HCP Study Area provides a unique opportunity to present known locations of dead Burrowing Owls.

METHODS

The locations of dead Burrowing Owls were recorded incidental to conducting capture-recapture population surveys during the prehatch stage of the breeding cycle (April) in 2007 and 2008. During the pilot study in 2006, we also conducted similar surveys along 412 Km of the IID's rights-of-way in April. During each year, a capture-recapture survey included 4 repeated occasions along asphalt and dirt roads paralleling water conveyance structures within the IID's rights-of-way. The specific survey methods were described in chapter 7. We also recorded information on dead Burrowing Owls observed along primary roads and highways we used to access the IID's rights-of-way. We traveled primary roads repeatedly throughout a field season, but we traveled along some more than others to gain quick access to the IID's rights-of-way. Thus, while our level of survey effort on the rights-of-way was constant within and between the 2007 and 2008 censuses, they were not equal among primary roads. The location coordinates of each dead Burrowing Owl were recorded with a hand-held GPS unit.

RESULTS

A total of 33 incidental observations of dead Burrowing Owls were recorded over the 3 years (Table IV.1). Their locations were spatially distributed across much of the HCP Study Area (Figure IV.1).

CONCLUSIONS AND RECOMMENDATIONS

The HCP Study Area is over 2,000 Km^2, dominated by agricultural activities, and encompasses a variety of urban, suburban, and rural human developments. Burrowing Owls in this system nest along irrigation drains and canals that border highways and

maintenance roads where vehicular activities can be high and maintenance activities frequent. Vehicle collisions have been cited as a potentially significant source of mortality (Haug et al. 1993, Clayton and Schmutz 1997), and the risk of vehicle collisions is likely greater in developed areas with dense human populations or along areas where owls nest predominately near roads. For example, higher post-fledging mortality from vehicle collisions occurred in an agricultural landscape with >90% of land area under cultivation compared to an unfragmented rangeland with <20% cultivation (Clayton and Schmutz 1997).

Inadvertent nest destruction from road maintenance activities in the HCP Study Area have been shown to effect survivorship of breeding Burrowing Owls in natural burrows along above-ground water conveyance structures (Catlin and Rosenberg 2006). However, the causes of mortality in this diverse area are likely to be numerous. The incidental observations presented here do not represent a complete set of locations where mortality occurs because the data collected here did not include the locations of dead owls outside of the IID rights-of-ways or those that were unavailable for detection during visual surveys from vehicles (e.g., inside burrows, concealed in vegetation like agricultural crops, or removed by predators, scavengers, or people).

Table IV.1. Count of dead Burrowing Owls by year in the Imperial Valley, California, 2006-2008. Data from 2006 are from a partial survey.

Year	Count of dead Burrowing Owls
2006	10
2007	15
2008	8

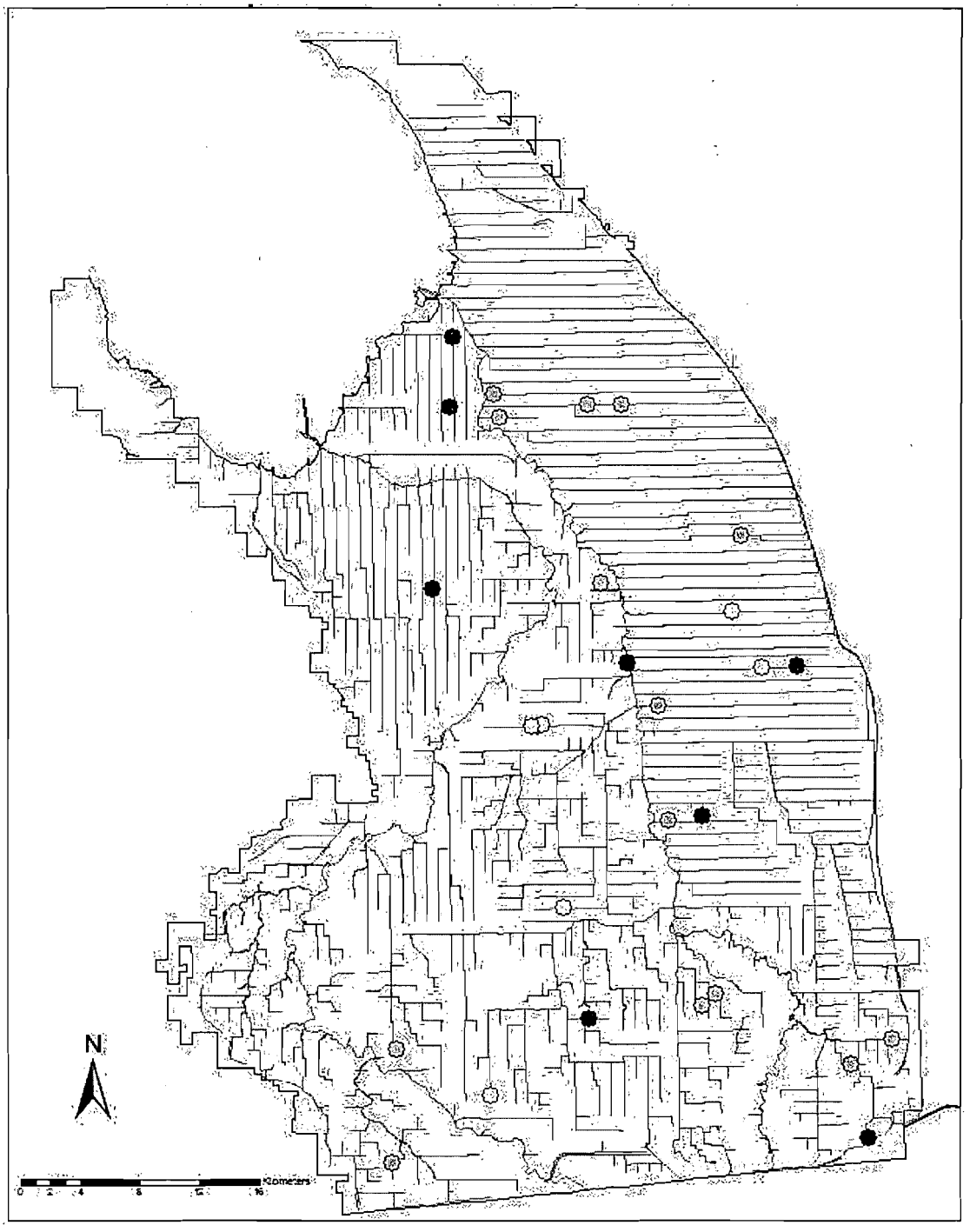


Figure IV.1. Locations of dead Burrowing Owls in the Imperial Valley, California, 2006-2008. Data from 2006 are from a partial survey. Solid black circles are locations of dead owls observed in 2006, solid grey circles are from 2007, and hollow circles are from 2008. Thin lines represent irrigation drains.

LITERATURE CITED

Catlin, D. H. and D. K. Rosenberg. 2006. Nest destruction associated with mortality and dispersal of Burrowing Owls in the Imperial Valley, California. The Southwest Naturalist 51:406-409.

Clayton, K. M. and J. K. Schmutz. 1997. Burrowing (Speotyto cunicularia) owl survival in prairie Canada. Pages 107-110 *in* J. R. Duncan, D. H. Johnson, and T. H. Nicholls (eds.). Biology and conservation of owls of the Northern Hemisphere: Second International Symposium. USDA, For. Serv. Gen. Tech. Rep. NC-190, North Central For. Exp. Station.

Haug, E. A., B. A. Millsap, and M. S. Martell. 1993. Burrowing Owl (Speotyto cunicularia). Mo. 61 *in* A. Poole and F. Gill (eds.). The Birds of North America, Academy of Natural Sciences and American Ornithological Union, Philadelphia, PA and Washington, DC USA

Appendix V

LOCATIONS OF BANDED OWLS IN 2006, 2007, AND 2008

JEFFREY A. MANNING

INTRODUCTION

There were 2 sources for reporting banded owls. The first was recording the locations of owls we banded during our various studies at the time we banded them. The second was locations of all banded owls (those we and others banded) incidentally detected while conducting standardized population surveys in 2007 and 2008. We detected no banded Burrowing Owls and did not band owls during the 2006 pilot study.

METHODS

See Chapters 2, 7,and 16 for details on banding and surveying methodologies.

RESULTS

We banded 94 Burrowing Owls in 2007 (Figure V.1, Table V.1).

In 2007, we incidentally detected 39 banded Burrowing Owls during the 4 survey occasions, and with equal survey effort during that same period in 2008, we detected 26 (Figure V.2, Tables V.2 and V.3).

CONCLUSIONS AND RECOMMENDATIONS

None.

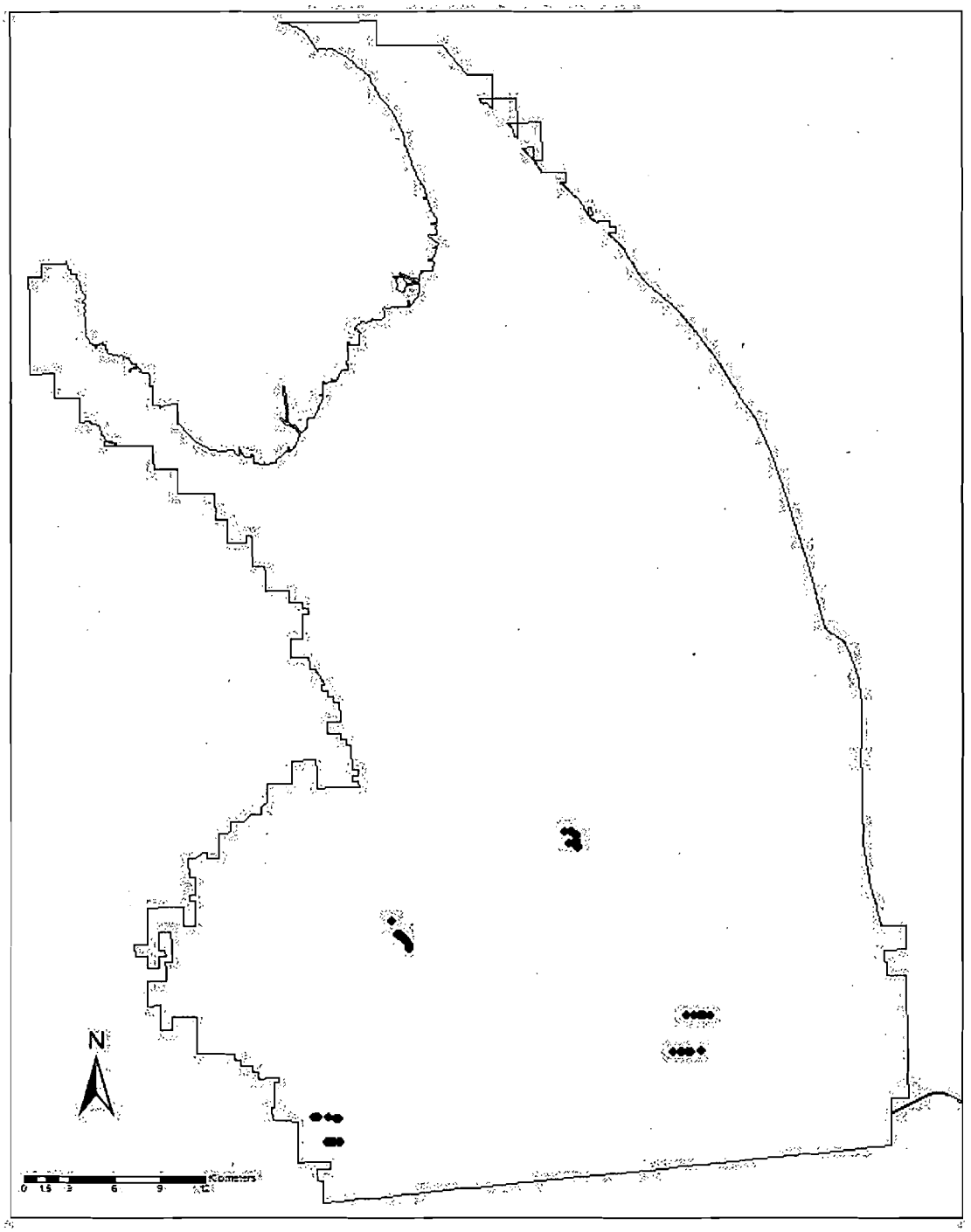


Figure V.1. Locations of Burrowing Owls banded in the HCP Study Area, Imperial County, California, 2007. Coordinates provided in Table V.1.

Table V.1. Coordinates of Burrowing Owls banded in the HCP Study Area, Imperial County, California, 2007.

Date	Bander Name	Color Band	Band No.	X	Y
2/16/2007	Jeff Kidd	Red	1	623713	3619031
2/16/2007	Jeff Kidd	Red	2	623811.7	3619034
2/16/2007	Jeff Kidd	Red	3	623959.4	3619036
2/17/2007	Jeff Kidd	Red	4	625182	3619001
2/17/2007	Jeff Kidd	Red	5	625182.4	3619000
2/17/2007	Jeff Kidd	Red	6	624828.3	3617379
2/17/2007	Jeff Kidd	Red	7	624972.6	3617380
2/17/2007	Jeff Kidd	Red	8	624829.3	3617379
2/17/2007	Jeff Kidd	Red	9	625105.9	3617383
2/17/2007	Jeff Kidd	Red	10	624663	3617402
2/17/2007	Jeff Kidd	Red	11	624867.9	3617402
3/3/2007	Jeff Kidd	Red	15	647949.6	3623291
3/3/2007	Jeff Kidd	Red	18	647948.7	3623287
3/3/2007	Jeff Kidd	Red	16	648302.2	3623288
3/3/2007	Jeff Kidd	Red	13	648357	3623289
3/3/2007	Jeff Kidd	Red	14	648356.7	3623289
3/3/2007	Jeff Kidd	Red	17	648542.9	3623293
3/3/2007	Jeff Kidd	Red	20	648542.8	3623293
3/3/2007	Jeff Kidd	Red	19	648428.9	3623295
3/3/2007	Jeff Kidd	Red	12	649153.1	3623363
3/3/2007	Jeff Kidd	Red	41	647324.3	3623279
3/3/2007	Jeff Kidd	Red	42	647814.7	3623282
3/3/2007	Jeff Kidd	Red	43	647814.6	3623282
3/3/2007	Jeff Kidd	Red	44	647397.2	3623281
3/3/2007	Jeff Kidd	Red	45	647394.5	3623280
3/9/2007	Jeff Kidd	Red	46	641029.8	3637478
3/9/2007	Jeff Kidd	Red	47	641029.7	3637557
3/9/2007	Jeff Kidd	Red	48	641035.6	3636840
3/9/2007	Jeff Kidd	Red	50	641032.7	3637176
3/9/2007	Jeff Kidd	Red	51	641035.3	3637036
3/9/2007	Jeff Kidd	Red	52	641038	3636838
3/9/2007	Jeff Kidd	Red	49	641028.9	3637559
3/9/2007	Jeff Kidd	Red	53	641035.8	3637037
3/9/2007	Jeff Kidd	Red	54	640507.9	3636976
3/9/2007	Jeff Kidd	Red	55	641032.8	3637175
3/9/2007	Jeff Kidd	Red	56	641039.3	3636759
3/9/2007	Jeff Kidd	Red	57	641039.4	3636759
3/10/2007	Jeff Kidd	Red	58	640660.3	3637789
3/10/2007	Jeff Kidd	Red	59	640660	3637788
3/10/2007	Jeff Kidd	Red	59	640564.6	3637787
3/10/2007	Jeff Kidd	Red	91	640203.3	3637784
3/16/2007	Jeff Kidd	Red	92	625054.5	3617377
3/16/2007	Jeff Kidd	Red	93	624971.3	3617378
3/16/2007	Jeff Kidd	Red	94	625426.9	3617402
3/17/2007	Jeff Kidd	Red	95	625426.3	3617403

3/17/2007	Jeff Kidd	Red	96	625311.7	3617400
3/17/2007	Jeff Kidd	Red	97	625313.5	3617400
3/17/2007	Jeff Kidd	Red	98	624574.3	3617394
3/17/2007	Jeff Kidd	Red	99	624575.2	3617394
2/17/2007	Scott Thomas	Red	40	624668.4	3619012
2/17/2007	Scott Thomas	Red	21	625285.2	3619000
2/18/2007	Scott Thomas	Red	30	625335.1	3618983
2/18/2007	Scott Thomas	Red	28	629692.3	3630666
2/18/2007	Scott Thomas	Red	31	629692.3	3630666
2/18/2007	Scott Thomas	Red	25	629566.2	3630789
2/18/2007	Scott Thomas	Red	22	629837.9	3630523
2/18/2007	Scott Thomas	Red	29	629526.5	3630827
3/4/2007	Scott Thomas	Red	23	629573.1	3630790
3/4/2007	Scott Thomas	Red	72	629612	3630749
3/4/2007	Scott Thomas	Red	27	629508.7	3630845
3/4/2007	Scott Thomas	Red	35	629527.2	3630828
3/4/2007	Scott Thomas	Red	38	629839.5	3630521
3/4/2007	Scott Thomas	Red	36	629936.1	3630449
3/4/2007	Scott Thomas	Red	32	629936.5	3630447
3/4/2007	Scott Thomas	Red	73	629352.6	3630951
3/4/2007	Scott Thomas	Red	70	629302.8	3631043
3/4/2007	Scott Thomas	Red	61	629241.2	3631047
3/5/2007	Scott Thomas	Red	65	629509.3	3630845
3/5/2007	Scott Thomas	Red	75	629516.9	3630842
3/5/2007	Scott Thomas	Red	80	629432.1	3630917
3/5/2007	Scott Thomas	Red	62	629375.1	3630972
3/11/2007	Scott Thomas	Red	77	629615.5	3630748
3/11/2007	Scott Thomas	Red	79	629378.5	3630970
3/11/2007	Scott Thomas	Red	74	629906.1	3630413
3/11/2007	Scott Thomas	Red	73	629353.2	3630949
3/11/2007	Scott Thomas	Red	71	629626.3	3630691
3/15/2007	Scott Thomas	Red	64	629943	3630315
3/15/2007	Scott Thomas	Red	76	628795.8	3631898
3/19/2007	Scott Thomas	Red	78	629760.6	3630598
3/19/2007	Scott Thomas	Red	69	629947.6	3630063
3/19/2007	Scott Thomas	Red	66	629947.8	3630128
3/19/2007	Scott Thomas	Red	69	629948.1	3630126
4/6/2007	Scott Thomas	Red	89	649807	3625701
4/5/2007	Pete Bloom	Red	81	649359.2	3625726
4/5/2007	Scott Thomas	Red	84	648733.1	3625721
4/5/2007	Scott Thomas	Red	83	648183.3	3625702
4/5/2007	Scott Thomas	Red	87	649223	3625720
4/5/2007	Scott Thomas	Red	90	649067.2	3625714
4/5/2007	Scott Thomas	Red	82	649067.3	3625716
4/5/2007	Scott Thomas	Red	88	649185.6	3625722
4/11/2007	Scott Thomas	Red	85	649807	3625701

Proj Coord Sys: NAD_83_UTM_Zone_11N; Proj: Transverse_Mercator; False_Easting: 500000.00000000; False_N.: 0.0000; Central_Meridian: -117.00000000; Scale_Factor: 0.9996; Lat_Of_Orig: 0.0000; Linear Unit: Meter; Geog Coord Sys: GCS_N._Am_83; Datum: D_N._Am._1983; Prime Merid: Greenwich; Ang. Unit: Degree.

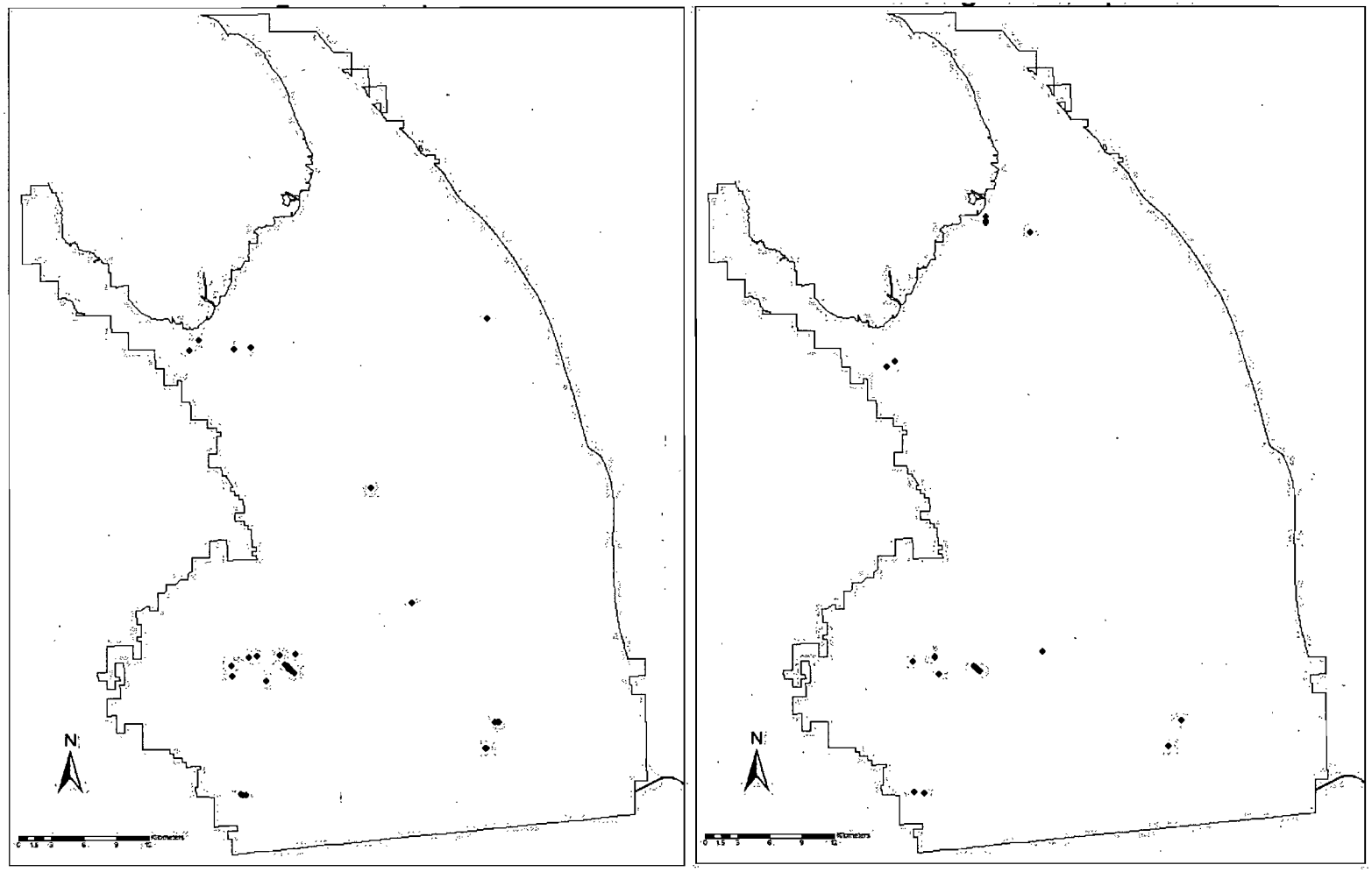


Figure V.2. Locations of banded Burrowing Owls incidentally detected during 4 survey occasions in the HCP Study Area, Imperial County, California, April 2007 and 2008. Coordinates provided in Table V.2 and V.3.

Table V.2. Coordinates of banded Burrowing Owls incidentally detected during 4 survey occasions in the HCP Study Area, Imperial County, California, April 2007.

Date	X	Y
4/13/2007	626143.9	3660471
4/17/2007	624625.1	3660246
4/11/2007	621292.5	3661131
4/10/2007	621286.5	3661137
4/10/2007	620439	3660210
4/3/2007	648014.3	3663108
4/16/2007	624371.7	3629942
4/2/2007	626709.7	3631777
3/30/2007	625936.9	3631667
4/16/2007	624332.3	3630938
4/2/2007	625936.8	3631666
4/3/2007	625400.5	3619003
4/3/2007	625185.5	3619018
4/5/2007	625936.8	3631667
4/5/2007	627541.8	3629430
4/9/2007	629761	3630600
4/9/2007	629841.6	3630522
4/9/2007	629907.7	3630411
4/9/2007	629637.3	3630660
4/10/2007	629762	3630598
4/10/2007	629840.9	3630522
4/10/2007	629907.5	3630413
4/10/2007	629639.9	3630658
4/10/2007	629537.3	3630930
4/11/2007	629303.8	3631044
4/11/2007	629378.6	3630971
4/11/2007	630157.4	3630208
4/11/2007	629639.3	3630658
4/4/2007	625936	3631666
4/10/2007	630302.6	3632004
4/18/2007	641037.6	3636758
4/3/2007	625611.8	3618963
4/5/2007	637334	3647406
4/10/2007	628798.7	3631897
4/16/2007	649066.7	3625714
4/16/2007	648732.2	3625710
4/16/2007	647815.8	3623283
4/16/2007	647946.8	3623287
4/16/2007	649043	3625693

Proj Coord Sys: NAD_83_UTM_Zone_11N; Proj: Transverse_Mercator; False_Easting: 500000.00000000; False_N.: 0.0000; Central_Meridian: -117.00000000; Scale_Factor: 0.9996; Lat_Of_Orig: 0.0000; Linear Unit: Meter; Geog Coord Sys: GCS_N._Am_83; Datum: D_N._Am._1983; Prime Merid: Greenwich; Ang. Unit: Degree.

Table V.3. Coordinates of banded Burrowing Owls incidentally detected during 4 survey occasions in the HCP Study Area, Imperial County, California, April 2008.

Date	Recorded by	C_COL_MARK	C_COL_CODE	C_CODE	C_LEG	M_CODE	M_LEG	X	Y
4/3/2008	Scott Thomas	none	none	none	none	not read	L	622283.89	3658990.45
4/3/2008	Elias Elias	red	white	F0	R	0934-28519	L	630751.55	3672046.22
4/3/2008	Elias Elias	red	white	A5	R	0934-28518	L	630770.85	3671792.06
4/9/2008	Scott Thomas	red	white	64	R	0804-42929	L	629943.84	3630314.54
4/9/2008	Scott Thomas	red	white	74	R	0804-42925	L	630157.64	3630203.55
4/3/2008	Jim Luttrell	none	none	none	none	not read	R	626359.23	3629912.22
4/3/2008	Jim Luttrell	red	white	1A	L	0844-80354	R	625937.19	3631537.48
4/4/2008	Scott Thomas	none	none	none	none	0934-26583	L	630764.48	3672384.55
4/4/2008	Scott Thomas	red	white	A6	R	0934-28516	L	630770.46	3671867.23
4/10/2008	Scott Thomas	red	white	32	R	0804-42913	L	629957.59	3630446.81
4/10/2008	Scott Thomas	red	white	25	R	0804-42907	L	629580.75	3630776.25
4/10/2008	Scott Thomas	red	white	78	R	0804-42932	L	629760.46	3630597.18
4/4/2008	Jim Luttrell	red	white	E9	L	not read	R	625937.53	3631605.71
3/31/2008	Jim Luttrell	red	white	2K	L	not read	R	623898.86	3631131.45
4/11/2008	Scott Thomas	red	white	36	R	0804-42911	L	629935.88	3630450.91
4/8/2008	Scott Thomas	none	none	none	none	not read	L	621453.64	3658495.59
4/14/2008	Scott Thomas	none	none	none	none	0804-06603	L	634942.72	3670977.96
4/7/2008	Mary Coolidge	Red	White	1	Left	not read	Right	623960.93	3619037.43
4/7/2008	Mary Coolidge	Red	White	5	Left	not read	Right	624939.11	3618985.12
4/8/2008	Mary Coolidge	Red	White	F4	Right	not read	Left	636113.57	3632078.82
4/11/2008	Mary Coolidge	Red	White	18	Left	not read	Right	647951.20	3623269.17
4/11/2008	Mary Coolidge	Red	White	43	Left	not read	Right	647818.17	3623267.20
4/11/2008	Mary Coolidge	Red	White	42	Left	not read	Right	647817.59	3623266.34
4/18/2008	Mary Coolidge	Red	White	82	Left	not read	Right	649122.42	3625714.18
4/23/2008	Mary Coolidge	Red	White	1A	Left	not read	Right	625938.45	3631530.67
4/24/2008	Mary Coolidge	Red	White	E9	Left	not read	Right	625935.92	3631626.01

Proj Coord Sys: NAD_83_UTM_Zone_11N; Proj: Transverse_Mercator; False_Easting: 500000.00000000; False_N.: 0.0000; Central_Meridian: -117.00000000; Scale_Factor: 0.9996; Lat_Of_Orig: 0.0000; Linear Unit: Meter; Geog Coord Sys: GCS_N._Am_83; Datum: D_N._Am._1983; Prime Merid: Greenwich; Ang. Unit: Degree.

Appendix VI

SELECTED COMMENTS AND REVIEWS

PETER BLOOM (Bloom Biological, Inc., Santa Ana, California)

Received report on December 10, 2008

From: phbloom1@aol.com <phbloom1@aol.com>
Subject: IID BUOW report
To: manningbiological@yahoo.com
Date: Thursday, December 11, 2008, 8:17 AM

Jeff, ... A most impressive document and something we can all feel proud of, thanks to you and the team you managed. ...

JEFF TUPEN (CH2M Hill, Sacramento, California)

Received report on December 10, 2008

From: "Jeff.Tupen@CH2M.com" <Jeff.Tupen@CH2M.com>
Subject: Draft IT notes from 12/11 meeting
To: andrew_thompson@fws.gov, BTippets@sdcwa.org, bwilcox@iid.com, carol_a_roberts@fws.gov, guy_wagner@fws.gov, jmgarber@iid.com, Jeff.Tupen@CH2M.com, jsheridan@dfg.ca.gov, KNICOL@dfg.ca.gov, skeeney@dfg.ca.gov, sgibson@dfg.ca.gov, tshields@iid.com
Cc: manningbiological@yahoo.com, PHBloom1@aol.com, LMacNair@dfg.ca.gov
Date: Tuesday, December 23, 2008 1:37 PM
2008 12-11 IT Meeting Notes draft.doc (55KB)

With respect to the Draft Report submitted by the Bloom team:

Overall, I think the document is very well done, and incredibly scholarly. It undoubtedly forms a solid basis for future BUOW survey efforts. This written, I'd suggest the following changes for Bloom team consideration (please feel free to add to, or rebut, my suggestions):

1. Define the Study Area early in the document, and use this term instead of the HCP area, or HCP. HCP Plan Area, Imperial Valley, and IID Service Area all come to mind as related terms, but I think Study Area, once defined, is the better term for this effort and deliverable.

2. Re-write/re-format the Executive Summary to more clearly communicate the important outcomes/results of the effort. Currently, its pretty method-heavy. I'm thinking something similar to the way that I've crafted the IT notes from the meeting. The current ES is 6.5 pgs...I suggest it can/should be pared to something less than 2.

3. I suggest reformatting to a more-traditional report format, and away from the thesis structure currently used. Pool all refs in single References section. Separating chapters is ok, but no need for

individual chapter authorship. If chapter authorship is important to others, this can be communicated in an Acknowledgements section of Forward section. I think this reorganization will improve the flow and readability of the document.

4. Cover sheet should reflect the contracted team effort. I suggest "Prepared by Bloom Biological, Inc., in association with Manning Biological Research and Wildlife Research Institute". I suspect Jeff Manning did the lions share of writing on this deliverable, but re-tooling the cover page ties this deliverable to IID contracting requirements more precisely.

5. Delete word "guise" globally from this document. The same is true for any other technically correct, but distracting terms. I'll defer to others for ferreting other terms out during review.

ANDREW THOMPSON (U.S. Fish and Wildlife Service, Carlsbad, California)

Received report on December 10, 2008

From: Andrew_Thompson@fws.gov [mailto:Andrew_Thompson@fws.gov]
Subject: RE: Draft IT notes from 12/11 meeting
To: Tupen, Jeff/SAC
Cc: Carol_A_Roberts@fws.gov
Date: Friday, February 06, 2009 5:00 PM
Comments on the Imperial Valley Burrowing Owl Population Study 2006 v2.doc (27KB)

Attachment: Comments on the Imperial Valley Burrowing Owl Population Study 2006 v2.doc (27KB)

Comments on the Imperial Valley Burrowing Owl Population Study 2006-2008

Jeff Manning and the Bloom Team have conducted extensive surveys in the Imperial Valley with the overriding goal of developing a protocol that accurately and cost-effectively samples burrowing owls in the future.

The report, overall, was excellent. They used the most up to date statistical methods to account for effects of sampling and methodological variability on estimates of owl population size. Their results provide clear guidance for an optimal strategy to generate acceptable levels of confidence around abundance estimates for a future sampling protocol.

One issue that was not completely resolved in my mind was the use of the spatial coordinates to generate capture histories. This method assumes that even if an owl is misidentified results will not be biases because detection probability will come out the same for the entire population. A potential problem with this assumption occurs if there is individual heterogeneity in the detection probability of owls. For example, if there is a proportion of the population that naturally has a lower detection probability, then assuming misclassification could bias the results. If there individual heterogeneity does not occur and misclassification is random, then the results would be unbiased.

It may be possible to resolve this issue by conducting a limited mark-recapture survey where owls are actually banded. Then, you could use model selection to determine whether a model that includes individual heterogeneity is selected over those that lack individual heterogeneity. If there is no evidence of individual heterogeneity, then we would achieve greater confidence in the use of spatial data in lieu of actual mark-recapture data. Given that they did band some owls to examine movement and site fidelity, maybe this data set could be used for such an evaluation.

As mentioned above, I agree with the recommendations given by the Bloom Team for measuring owl abundance in the future. One aspect we need to think about, however, is how to better establish the types of management activities that could alleviate population declines. The report showed that there was an appreciable decline in owl abundance between 2007 and 2008 and tells us what we need to do to be able to detect changes in the future. It is unknown what caused this decline, however, and thus the results do not provide guidance for management actions. Given that even the most highly selected models described only a small (yet significant) proportion of the variation in owl abundance, there is a need to more precisely explain potential causes of population fluctuation. It is possible that the covariates collected by the Bloom Team were too coarse and thus operated at a different spatial scale than what affects the owls. It is also possible that the decline was caused by something that went on outside of the Imperial Valley. Our task is now to determine whether factors within our control are impacting owls and provide guidance for how management can minimize detrimental factors.

A first step might be to evaluate the relationship of covariates to owls in 2008. The strongest models from 2007 identified the current number of burrows (Burrows in 2007) and alfalfa 3 and 4 years prior as correlating with owl abundance. Based on this finding, an expectation would be that alfalfa in 2005 would more strongly correlate with 2008 owls than 2007 owls. Is this the case? To further the goal of understanding how to adaptively manage this species it will be necessary to evaluate further the effect of covariates on burrowing owl distribution and abundance.

U.S. Fish & Wildlife Service

Status Assessment and Conservation Plan for the Western Burrowing Owl in the United States

Biological Technical Publication

BTP-R6001-2003

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U.S. Fish & Wildlife Service

Status Assessment and Conservation Plan for the Western Burrowing Owl in the United States

Biological Technical Publication

BTP-R6001-2003

David S. Klute[1,7] William H. Howe[4] Steven R. Sheffield[6,9]

Loren W. Ayers[2,8] Stephanie L. Jones[1] Tara S. Zimmerman[3]

Michael T. Green[3] Jill A. Shaffer[5]

[1] U.S. Fish and Wildlife Service, Region 6, Nongame Migratory Bird Program, Denver, CO

[2] Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, Laramie, WY

[3] U.S. Fish and Wildlife Service, Region 1, Nongame Migratory Bird Program, Portland, OR

[4] U.S. Fish and Wildlife Service, Region 2, Nongame Migratory Bird Program, Albuquerque, NM

[5] U.S. Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, ND

[6] U.S. Fish and Wildlife Service, Office of Migratory Bird Management, Arlington, VA

[7] Current Address: Colorado Division of Natural Resources

[8] Current Address: Wisconsin Department of Natural Resources

[9] Current Address: George Mason University

Author contact information:

David S. Klute, (Current address) Colorado Division of Wildlife, 6060 Broadway, Denver, CO 80216. Phone: (303) 291-7320, Fax: (303) 291-7456, e-mail: David.Klute@state.co.us.

Loren W. Ayers, (Current address) Bureau of Integrated Science Services, Wisconsin Department of Natural Resources, 101 S. Webster St., Madison, WI 53707-7921. Phone: (608) 261-6449, Fax: (608) 266-5226, e-mail: ayersl@mail01.dnr.state.wi.us.

Michael T. Green, U.S. Fish and Wildlife Service, Region 1, Nongame Migratory Bird Program, 911 Northeast 11th Avenue, Portland, OR 97232. Phone: (503) 231-6164, Fax: (503) 231-6164, e-mail: Michael_Green@fws.gov.

William H. Howe, U.S. Fish and Wildlife Service, Region 2, Nongame Migratory Bird Program, P.O. Box 1306, Albuquerque, NM 87103. Phone: (505) 248-6875, Fax: (505) 248-6674, e-mail: Bill_Howe@fws.gov.

Stephanie L. Jones, U.S. Fish and Wildlife Service, Region 6, Nongame Migratory Bird Program, P.O. Box 25486 DFC, Denver, CO 80225-0486. Phone: (303) 236-4409, Fax: (303) 236-8680, e-mail: Stephanie_Jones@fws.gov.

Jill A. Shaffer, U.S. Geological Survey, Northern Prairie Wildlife Research Center, 8711 37th St. SE, Jamestown, ND 58401. Phone: (701) 253-5547, Fax: (701) 253-5553, e-mail: jshaffer@usgs.gov.

Steven R. Sheffield, (Current address) Department of Biology, George Mason University, Fairfax, VA 22030, e-mail: srsheffield@att.net.

Tara S. Zimmerman, U.S. Fish and Wildlife Service, Region 1, Nongame Migratory Bird Program, 911 Northeast 11th Avenue, Portland, OR 97232. Phone: (503) 231-6164, Fax: (503) 231-6164, e-mail: Tara_Zimmerman@fws.gov.

For additional copies or information, contact:
Nongame Migratory Bird Program
U.S. Fish and Wildlife Service
P.O. Box 25486 DFC
Denver, CO 80225-0486

Recommended citation:
Klute, D. S., L. W. Ayers, M. T. Green, W. H. Howe, S. L. Jones, J. A. Shaffer, S. R. Sheffield, and T. S. Zimmerman. 2003. Status Assessment and Conservation Plan for the Western Burrowing Owl in the United States. U.S. Department of Interior, Fish and Wildlife Service, Biological Technical Publication FWS/BTP-R6001-2003, Washington, D.C.

Table of Contents

Table of Contents iii

List of Figures vi

List of Tables viii

Executive Summary 1

Acknowledgments 2

Taxonomy 3

Legal Status 4
United States 4
Canada 4
Mexico 4

Description 6

Distribution 7
Breeding 7
Migration 7
Winter 7

Natural History 10
Breeding 10
- Phenology 10
- Diet 10
- Foraging 10
- Productivity 10
- Territory 10
- Aggregations 10
- Mortality and Predation 11
- Site and Burrow Fidelity 11

Habitat 12
Breeding 12
Migration 12
Winter 12

Populations 13
Population Estimates and Trends 13
- Breeding Bird Survey 13
- Christmas Bird Count 13
- Other Surveys, United States 13
- Other Surveys, Canada 17
- Other Surveys, Mexico 17

Densities 17
Changes in Breeding Season Distribution 17
- United States 17
- Canada 19
- Mexico 19

Re-occupancy Rates 19

Monitoring Activities 20
Range-wide Surveys 20
Local Surveys 20
Proposed Protocols and Surveys 20

Threats 21
Habitat: Breeding 21
Habitat Loss and Fragmentation 21
Burrows 21
Grazing 21
Burning 21
Mowing 22
Habitat: Winter 22
Overutilization For Commercial, Recreational, Scientific, or Educational Purposes 22
Predation and Disease 22
Predation 22
Disease 22
Inadequacy of Existing Regulatory Mechanisms 22
Other Natural or Manmade Factors 22
Disturbance at Nest and Roost Sites 22
Ingestion of Plastics, Lead, Etc. 22
Collisions with Stationary/Moving Structures 22
Shooting, Trapping, and Hunting 22
Population Size and Isolation 22
Introduced Species 22
Indirect Effects of Disease 22
Pesticides and Other Contaminants/Toxics 23

Recommendation on Current Conservation Status 24

Management and Conservation 25
Habitat 25
Habitat Features 25
Fire 25
Mowing 25
Grazing 25
Burrowing Mammals 25
Reintroduction and Relocation 26
Reintroduction 26
Relocations and Artificial Burrows 26
Pesticide Use 26
Monitoring 26
Migration 27
Wintering Areas 27
Education 27
Current Activities and Programs 27
United States 27
Canada 28

Research Needs 29

Literature Cited 30

Appendix A: State Summaries of Burrowing Owl Status **36**
Arizona 36
California 40
Colorado 45
Florida 48
Idaho 53
Iowa 56
Kansas 57
Minnesota 59
Montana 60
Nebraska 63
Nevada 66
New Mexico 69
North Dakota 72
Oklahoma 75
Oregon 77
South Dakota 80
Texas 82
Utah 83
Washington 84
Wyoming 87
Arkansas, Illinois, Missouri, Wisconsin 90

Appendix B: Summary of Conservation Recommendations for Burrowing Owls **91**

Appendix C: Distribution List for the Burrowing Owl Status Assessment and Conservation Plan **94**

Appendix D: Scientific and Common Names of Animals and Plants Mentioned in the Burrowing Owl Status Assessment and Conservation Plan **106**

List of Figures

Fig. 1. Current and historical ranges of the Western Burrowing Owl in North America; modified from the Birds of North America species account (Haug et al. 1993), North American Breeding Bird Survey distribution map (Sauer et al. 2001), individual papers from the Proceedings of the Second International Burrowing Owl Symposium (Journal of Raptor Research 35(4) 2001), and personal communications with local experts. Historical range (pre-1970's) taken from Zarn (1974), Wedgwood (1978), and from personal communications with local experts. In states that lacked detailed distributional data, Burrowing Owls were presumed to be absent from areas of forest or rugged mountains. The historical range is unknown for Mexico (from Wellicome and Holroyd 2001). 8

Fig. 2. Burrowing Owl distribution in Mexico during the breeding (16 April – 15 October) and non-breeding (16 October – 15 April) seasons as determined from 279 museum specimens and literature documentation (Enriquez-Rocha 1997). 9

Fig. 3. Winter distribution of the Burrowing Owls in the United States from Christmas Bird Count (CBC) data (1966-1989). Shading represents the species relative abundance (birds/100 party hours) averaged for each CBC circle and smoothed over the species distribution (Sauer et al. 1996). 11

Fig. 4. Breeding Bird Survey trends for Burrowing Owls in the United States and Canada (1966-96, Sauer et al. 2002). These trends do not necessarily reflect statistical significance (see Table 2). 16

Fig. A-1. Distribution of the Burrowing Owl in Arizona from the Arizona Breeding Bird Atlas project (Arizona Breeding Bird Atlas, Unpubl. data (1993-2001), C. Wise, pers. commun.). 37

Fig. A-2. Distribution of Burrowing Owl Populations in California, 1991-1993 (9,266 breeding pairs, estimate) (DeSante et al. unpubl. ms.). 41

Fig. A-3. Distribution of Burrowing Owls in Colorado from the Colorado Breeding Bird Atlas project (Jones 1998). 46

Fig. A-4. Distribution of Burrowing Owls in Kansas from the Kansas Breeding Bird Atlas project (Busby and Zimmerman 2001). 58

Fig. A-5. Latilong distribution of Burrowing Owls in Montana. B = direct evidence of breeding, b = indirect evidence of breeding, t = species observed, but no evidence of breeding (Montana Bird Distribution Committee 1996). 61

Fig. A-6. Distribution of Burrowing Owls in Nebraska, based on breeding evidence post-1960 (Ducey 1988). 64

Fig. A-7. Distribution of Burrowing Owls in Nevada from the Nevada Breeding Bird Atlas project (Unpubl. data). 67

Fig. A-8. Distribution of Burrowing Owls in North Dakota, prior to 1972. Filled squares = nest or dependent young recorded from 1950 to 1972. Empty squares = nests or dependent young recorded prior to 1950. Filled triangles = territorial males or pairs recorded from 1950 to 1972. Empty triangles = territorial males or pairs recorded prior to 1950 (Stewart 1975). 73

Fig. A-9. Distribution of Burrowing Owls in Oklahoma (Oklahoma Breeding Bird Atlas Project, D. Reinking, pers. commun.). 76

Fig. A-10. Distribution of confirmed (n = 49), probable (n = 9), and possible (n = 37) breeding activity of Burrowing Owls in Oregon from the Oregon Breeding Bird Atlas project (Adamus et al. 2001). 78

Fig. A-11. Distribution of Burrowing Owl breeding activity and observation in South Dakota from the South Dakota Breeding Bird Atlas project (Peterson 1995). 81

Fig. A-12. Distribution of Burrowing Owl observations in Utah (Utah Natural Heritage Program, A. Axel, pers. commun.). 83

Fig. A-13. Distribution of Burrowing Owls burrows in Washington (Washington Department of Fish and Wildlife, Wildlife Resources Data System, J. Brookshier, pers. commun.). 85

Fig. A-14. Historic Burrowing Owl records (dots) from the Wyoming Game and Fish Department Wildlife Observation System and reoccupancy survey sites with Burrowing Owls (diamonds) in 1999 (from Korfanta et al. 2001). 88

Fig. A-15. Numbers of Burrowing Owl records per year in the Wyoming Game and Fish Department Wildlife Observation System. The trend line for the 1986 – 1997 period represents a period of presumed consistent search effort (from Korfanta et al. 2001). 88

List of Tables

Table 1. Legal status and natural heritage status of Burrowing Owls in the United States, Canada, and Mexico. 5

Table 2. North American Breeding Bird Survey trends, significance level (P), sample size (n) and 95% confidence intervals (CI) for the Burrowing Owl during three different survey periods (Sauer et al. 2002). 14

Table 3. Christmas Bird Count trends, sample sizes (n), 95% confidence intervals (CI), significance levels (P), and relative abundance (RA) for the Burrowing Owl in areas with sufficient data for analysis, 1959-1988 (Sauer et al. 1996). 16

Table 4. Burrowing Owl population estimates for states, provinces, and countries. James and Espie (1997) surveyed state/provincial biologists in 1992 to determine approximate total breeding populations. Other populations estimates are presented only for statewide/province-wide estimates; additional local population estimates can be found in Appendix A: State Summaries of Burrowing Owl Status. 18

Table A-1. Comparison of mean density, survival, and reproductive rates of Burrowing Owls at four sites in California.. 42

Table A-2. Estimates of juvenile survival rates necessary for population stability under different adult reproductive and survival rates. 42

Table A-3. Distribution and abundance of Florida Burrowing Owls by major subpopulation and county. . . . 50

Table A-4. Number of occupied, unoccupied, destroyed, and not found Burrowing Owl nests located in Washington during Washington Department of Fish and Wildlife surveys in 1999 and 2000. 85

Table B-1: General categories of conservation recommendations for Burrowing Owls from states for which recommendations were found. 92

Table D-1: Scientific and common names of animals mentioned in the “Status Assessment and Conservation Plan for the Western Burrowing Owl in the United States”. 111

Table D-2: Scientific and common names of plants mentioned in the “Status Assessment and Conservation Plan for the Western Burrowing Owl in the United States”. 113

Executive Summary

The Western Burrowing Owl (*Athene cunicularia hypugaea*) is a grassland specialist distributed throughout w. North America, primarily in open areas with short vegetation and bare ground in desert, grassland, and shrub-steppe environments. Burrowing Owls are dependent on the presence of fossorial mammals (primarily prairie dogs and ground squirrels), whose burrows are used for nesting and roosting. Burrowing Owls are protected by the Migratory Bird Treaty Act in the United States and Mexico. They are listed as Endangered in Canada and Threatened in Mexico. They are considered by the U.S. Fish and Wildlife Service (USFWS) to be a Bird of Conservation Concern at the national level, in three USFWS regions, and in nine Bird Conservation Regions . At the state level, Burrowing Owls are listed as Endangered in Minnesota, Threatened in Colorado, and as a Species of Concern in California, Montana, Oklahoma, Oregon, Utah, Washington, and Wyoming.

Burrowing Owls historically bred from sc. and sw. Canada southward through the Great Plains and w. United States and south to c. Mexico. Although the historical breeding range is largely intact, range contractions have occurred primarily at peripheral regions, in s. Canada, the ne. Great Plains, and parts of California and the Pacific Northwest. Burrowing Owls winter in the sw. and sc. United States, throughout Mexico, and occasionally as far south as Panama.

Populations of Burrowing Owls have declined in several large regions, notably in the ne. Great Plains and Canada. However, estimates of population trends in many regions are generally inconclusive due to small samples sizes and high data variability. Population trends as determined from North American Breeding Bird Survey (BBS) data were inconsistent, with some regions exhibiting positive trends and other regions exhibiting negative trends. When taken as a whole, the BBS indicated an area of generally declining populations in the northern half of the Great Plains, and generally increasing populations in the interior U.S. and in some southwestern deserts. The Christmas Bird Count indicated a significant population decline in California (1966-1989). Local surveys have detected declining populations and/or range reductions in California, Iowa, Kansas, Minnesota, Nebraska, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Washington, and throughout the range of the species in Canada.

Primary threats across the North American range of the Burrowing Owl are habitat loss due to land conversions for agricultural and urban development, and habitat degradation and loss due to reductions of burrowing mammal populations. The elimination of burrowing mammals through control programs and habitat loss has been identified as the primary factor responsible for declines of Burrowing Owls. Additional threats to Burrowing Owls include habitat fragmentation, predation, illegal shooting, pesticides and other contaminants. The types and significance of threats during migration and wintering are poorly understood.

The preservation of native grasslands and populations of burrowing mammals is ultimately critical for the conservation of Burrowing Owls. Efforts to maintain and increase populations of burrowing mammals through reduction of lethal control programs and landowner and land manager education should be undertaken. Burning, mowing, and grazing may be employed to maintain suitable habitat structure for nesting Burrowing Owls, although additional research is needed. Efforts to reintroduce or relocate Burrowing Owls should be critically reviewed to determine efficacy and best methods. Current large-scale monitoring efforts are generally inadequate. Effective programs to better determine actual population trends and demographics of Burrowing Owl populations should be developed and implemented.

Acknowledgments

Many individuals contributed significant time, literature, and expertise to this review including: R. Anthony, A. Axel, P. Arrowood, E. Atkinson, A. Bammann, J. Barclay, J. Belthoff, J. Brookshier, N. Brown, K. Brunson, D. Buckland, K. Burton, W. Busby, K. Butts, K. Clayton, L. Cole, C. Collins, C. Conway, T. Corman, E. Cummings, C. Cwiklinski, N. Dawson, K. De Smet, M. Desmond, J. Dinsmore, B. Domagalski, E. Dowd-Stukel, F. Esparza, C. Finley, T. Floyd, L. Fredrickson, D. Freed, J. Freilich, J. Friday, S. Grassel, R. Griebel, D. Harvey, M. Hetrick, B. Hodorff, G. Holroyd, S. Houston, M. Howery, S. Hutchings, L. Igl, D. Keinath, S. Kendall, N. Korfanta, J. Lincer, M. Lockwood, M. Martell, D. Mehlman, B. Millsap, P. Mineau, S. Moore, R. Murphy, J. Parrish, R. Peterson, D. Plumpton, D. Reinking, T. Rich, D. Rintoul, L. Romin, M. Rowe, C. Rustay, L. Sager, K. Scalise, J. Schmutz, C. Shackelford, G. Skiba, M.K. Skoruppa, J. Slater, K. Steenhof, C. Stowers, L. Trulio, T. Uhmann, T. VerCauteren, B. Vermillion, T. Wellicome, R. Williams, J. Winter, C. Wise, M. Woodin, J. Woollett, and J. Yamamoto.

Special thanks to G. Holroyd and T. Wellicome, with the Canadian Wildlife Service, for assistance in gathering literature, providing maps and graphs, and making contacts. Special thanks also to D. Rosenberg for providing additional information and thorough reviews. T. Uhmann and N. Brown provided bibliographies. M. J. Cowing and the Richard R. Olendorff Memorial Library at the Forest and Rangeland Ecosystem Science Center provided extensive literature. P. Sutherland provided assistance compiling the literature and editing the manuscript. Thanks also to D. Dark, K. Sims, and L. Semo for assistance with literature review, compiling, and editing. Thanks to A. Araya for providing valuable assistance.

We thank the following for providing reviews of an earlier draft: J. Barclay, B. Busby, J. Dillon, C. Finley, K. M. Giesen, D. B. Hall, L. Hanebury, G. Holroyd, N. Korfanta, D. W. Mehlman, E. J. Miller, R. K. Murphy, D. Rosenberg, J. S. Shackford, S. Sherrod, K. Steenhof, T. VerCauteren, and R. D. Williams.

Taxonomy

Two subspecies of Burrowing Owl (*Athene cunicularia*) occur in North America: the Western Burrowing Owl (*A. c. hypugaea*) and the Florida Burrowing Owl (*A. c. floridana*). Although this status assessment is focused on North American populations of the Western Burrowing Owl (henceforth Burrowing Owl), a state summary for the Florida Burrowing Owl is included in this document (Appendix A) to provide complete information on the species in the United States. The Florida state summary is an update of information included in Millsap (1996).

Class: Aves

Order: Strigiformes

Family: Strigidae

Genus: *Athene*

Species: *A. cunicularia*

Subspecies: *A. c. hypugaea*, *A. c. floridana*

Authority: (Molina, Subspp. Bonaparte)

Originally named *Strix cunicularia* by Molina in 1782, the Burrowing Owl received several taxonomic changes until placed in the genus *Speotyto* and now *Athene* (Clark et al. 1997, AOU 1998). *A. cunicularia* occurs as a breeding and/or wintering species throughout w. North America, Central America, and extensive portions of South America with disjunct populations in Florida and the Caribbean Islands. *A. c. hypugaea* occurs in North America to the eastern limits of the Great Plains and from s. British Columbia to Manitoba and into Central America as far south as Panama (Haug et al. 1993). This subspecies occurs primarily in prairies, grasslands, shrub-steppe, desert, and agricultural areas in North America (Haug et al. 1993). *A. c. floridana* occurs in Florida north to Madison and Duval counties (AOU 1998).

Legal Status

United States

From 1994-1996, the Western Burrowing Owl was designated by the U.S. Fish and Wildlife Service (USFWS) as a Category 2 species for consideration to be listed as a threatened or endangered species. In 1996 the Category 2 designation was discontinued. The Burrowing Owl currently is federally protected by the Migratory Bird Treaty Act (1918) in the United States and Mexico. The Western Burrowing Owl is listed by the USFWS as a National Bird of Conservation Concern (U.S. Fish and Wildlife Service 2002). It is also listed as a Bird of Conservation Concern in USFWS Regions 1 (Pacific Region, mainland only), 2 (Southwest Region), and 6 (Mountain-Prairie Region) as well as in Bird Conservation Regions (BCR) 9 (Great Basin), 11 (Prairie Potholes), 16 (S. Rockies/Colorado Plateau), 17 (Badlands and Prairies), 18 (Shortgrass Prairie), and U.S. Portions of BCR 32 (Coastal California), 33 (Sonoran and Mojave Deserts), 35 (Chihuahuan Desert) and 36 (Tamaulipan Brushlands) (U.S. Fish and Wildlife Service 2002). The Burrowing Owl is listed as Endangered, Threatened, or as a Species of Concern in 9 states and 4 Canadian provinces (Table 1). It is given a Global Heritage Status Rank of G4 (apparently secure globally though it may be quite rare in parts of its range) and is listed as a Convention on International Trade in Endangered Species (CITES), Appendix II species (NatureServe Explorer 2001).

Canada

In 1979, the Western Burrowing Owl was listed as "Threatened" based on Wedgwood (1979), reconfirmed in 1991 (Haug and Didiuk 1991), and changed to "Endangered" in 1995 (Wellicome and Haug 1995).

Mexico

In 1994, Burrowing Owls were listed as a federally Threatened (Amenazadas) species (Secretaria de Desarollo Social de Mexico 1994 *in* Sheffield 1997*a*).

Table 1. Legal status and natural heritage status of Burrowing Owls in the United States, Canada, and Mexico

Area	Legal status	Natural Heritage status[a]
United States	None	Apparently Secure
Arizona	None	Vulnerable
California	Species of Concern	Imperiled
Colorado	Threatened	Apparently Secure
Idaho	None	Vulnerable/Apparently Secure
Iowa	Accidental breeder	Unranked
Kansas	None	Vulnerable
Minnesota	Endangered	Critically Imperiled
Montana	Species of Concern	Vulnerable
Nebraska	None	Vulnerable
Nevada	None	Vulnerable
New Mexico	None	Apparently Secure
North Dakota	None	Unranked
Oklahoma	Species of Concern	Vulnerable
Oregon	Species of Concern	Imperiled
South Dakota	None	Vulnerable/Apparently Secure
Texas	None	Vulnerable
Utah	Species of Concern	Vulnerable
Washington	Species of Concern	Vulnerable
Wyoming	Species of Concern	Vulnerable
Canada	Endangered	Vulnerable
Alberta	Endangered	Vulnerable
British Columbia	Endangered	Critically Imperiled
Manitoba	Endangered	Critically Imperiled
Saskatchewan	Endangered	Imperiled
Mexico	Threatened	Unranked

[a]–Global status = Apparently Secure

Description

The Burrowing Owl is a small owl (19.5-25.0 cm, ~150 g), with long slender tarsi covered with short hair-like feathers that terminate in sparse bristles on the feet. The head is rounded, lacks ear tufts, and is chocolate in color with white streaking or spotting. There are buffy-white margins around the eyes and a white throat patch. Eyes are lemon-yellow and the beak is pale horn-colored. The wings are relatively long and rounded, the tail is short, and both are brown with buff-white barring. The undertail coverts are white. The dorsal area including head, back, and scapulars are heavily spotted with buffy-white. The belly of adults is buffy and heavily barred with brown on the sides. Juveniles are similar to adults but are unstreaked to lightly streaked, light to brownish buff below, and have more pale secondary coverts (Haug et al. 1993). The Burrowing Owl is the only North American strigiform not exhibiting reversed size dimorphism (Haug et al. 1993).

Distribution

Breeding

In Canada, the historical breeding range of the Burrowing Owl includes se. British Columbia, s. Alberta, s. Saskatchewan, and sw. Manitoba (Fig. 1, Haug et al. 1993, Wellicome and Holroyd 2001). In the United States the historical breeding range includes e. Washington and Oregon, s., c. and e. California, c. and e. Montana, s. Idaho, Utah, Nevada, Arizona, Wyoming, Colorado, New Mexico, North Dakota, South Dakota, Nebraska, w. and c. Kansas, w. and c. Oklahoma, w. Minnesota, nw. Iowa, and most of w. Texas (Fig. 1). The breeding range has contracted primarily on the eastern and northern edges (Wellicome and Holroyd 2001). Anecdotal observations suggest accidental breeding may have occurred in Wisconsin (R. Domalgalski, pers. commun.). Migrants or vagrants have been documented in Louisiana (B. Vermillion, pers. commun.), Missouri (Haug et al. 1993), Arkansas (James and Neal 1986), and Illinois (Illinois Natural History Information Network 2000). The breeding range extends south to c. Mexico (Fig. 1, Fig. 2) (Enriquez-Rocha 1997, Wellicome and Holroyd 2001).

Migration

Little information exists on migration routes and times. Burrowing Owls migrate north during March and April, arriving the first week of May in Saskatchewan (Haug et al. 1993). The majority of Burrowing Owls that breed in Canada and the n. United States are believed to migrate south during September and October.

Burrowing Owls banded in British Columbia, Washington, Oregon, and California migrated southward along the Pacific coast. Burrowing Owls banded in Alberta, Saskatchewan, Manitoba, Montana, and North Dakota migrated southward through Nebraska and Kansas into Texas. One Burrowing Owl from Manitoba was recovered in the Gulf of Mexico. Burrowing Owls banded in Wyoming, South Dakota, Nebraska, Colorado, Kansas, and Oklahoma have been recovered in Arkansas, Oklahoma, Texas, and Mexico. Recoveries indicate that some Burrowing Owls will winter in California and Baja California, Mexico. Burrowing Owls breeding in North and South Dakota are believed to winter in Texas.

Winter

The small number of banding recoveries (n = 27, 1927 through 1990) provides little information regarding wintering areas (Haug et al. 1993). Burrowing Owls winter regularly from Mexico (Fig. 2) to El Salvador and are casual to accidental to w. Panama (AOU 1998). They are recorded on the Christmas Bird Count (CBC) in Arizona, California, New Mexico, Oregon, Texas, and Mexico (Fig. 3; James and Ethier 1989). They will also winter north of these states, particularly in Oklahoma and Kansas, in very low abundance. They will also winter in low abundance in sc. Nevada (Hall et al. *In review*).

Little information exists on Burrowing Owls in Mexico and breeding and wintering areas have not been well described. Based on museum specimens, the Burrowing Owl is the third most common owl species in the country and sixty-three percent of museum specimens (n = 279) from Mexico were collected in the non-breeding season (Enriquez-Rocha 1997); however, it is unlikely that these collections reflect true relative abundance. These collections documented a wide distribution, occurring in 28 of the 32 Mexican states. Non-breeding data were from the Pacific region, some central states, and from the se. Gulf of Mexico (including the Yucatan Peninsula). Both breeding and nonbreeding records document Burrowing Owls in n. Mexico, Baja California, and some states from the Gulf of Mexico.

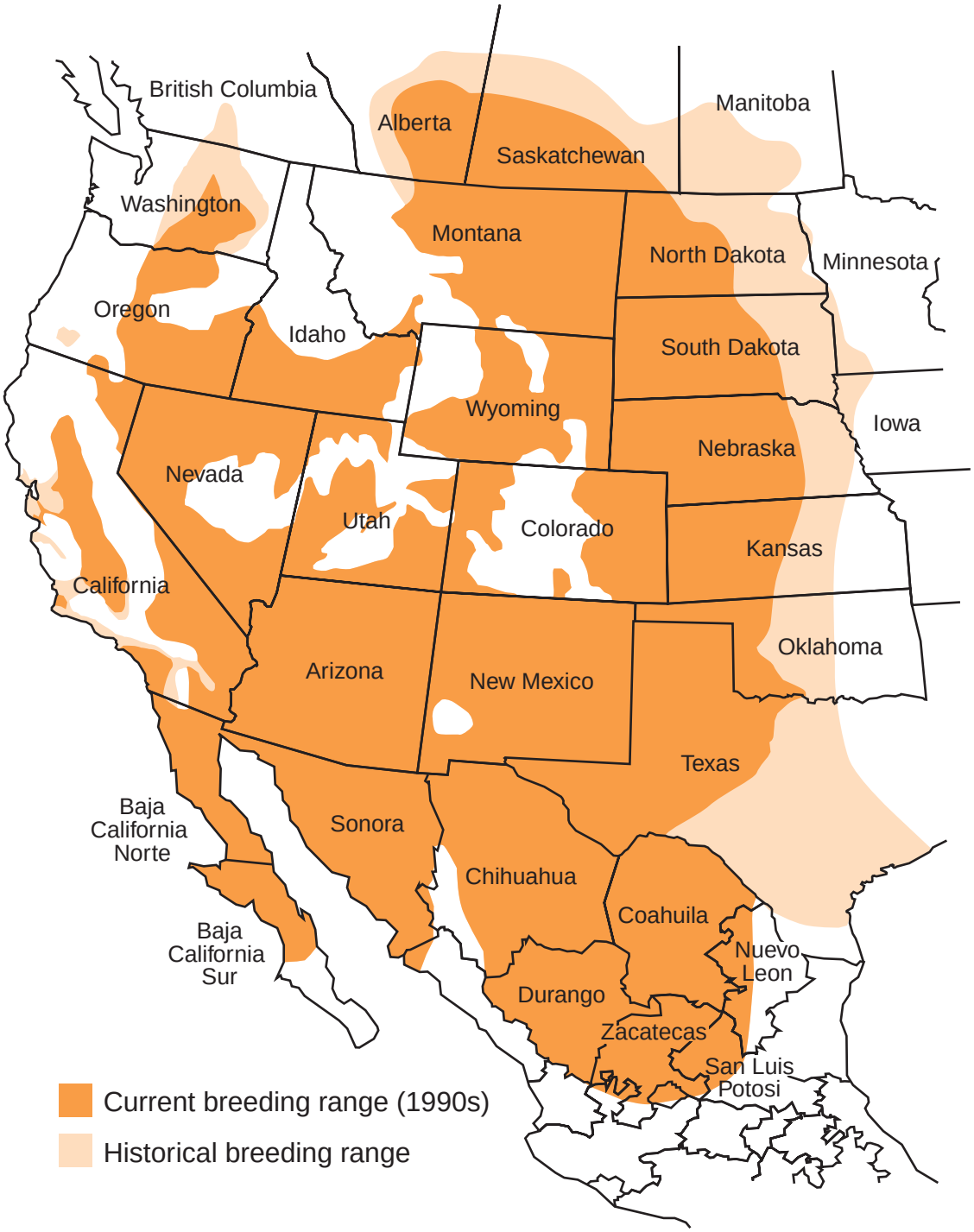

Fig. 1. Current and historical ranges of the Western Burrowing Owl in North America; modified from the Birds of North America species account (Haug et al. 1993), North American Breeding Bird Survey distribution map (Sauer et al. 2001), individual papers from the Proceedings of the Second International Burrowing Owl Symposium (Journal of Raptor Research 35(4) 2001), and personal communications with local experts. Historical range (pre-1970's) taken from Zarn (1974), Wedgwood (1978), and from personal communications with local experts. In states that lacked detailed distributional data, Burrowing Owls were presumed to be absent from areas of forest or rugged mountains. The historical range is unknown for Mexico (from Wellicome and Holroyd 2001).

Fig. 2. Burrowing Owl distribution in Mexico during the breeding (16 April – 15 October) and non-breeding (16 October – 15 April) seasons as determined from 279 museum specimens and literature documentation (Enriquez-Rocha 1997).

Natural History

Breeding

Phenology—Burrowing Owls are generally found on the northern breeding grounds from mid-March through September (Haug et al. 1993). Courtship and pair formation occur in March and April in most areas (Grant 1965, Butts 1973) but may begin as early as late December in California (Thomsen 1971).

Incubation lasts 28-30 days and is performed by the female (Coulombe 1971, Thomsen 1971, Haug et al. 1993). The young begin feathering out at two weeks of age. The young run and forage by four weeks of age and are capable of sustained flight by six weeks. Burrowing Owl families often switch burrows every 10-15 days when the young are three to four weeks old and remain as a loose-knit group until early fall when the young may begin to disperse to nearby burrows (Haug et al. 1993, Dechant et al. 1999).

Diet—Burrowing Owls are opportunistic feeders, primarily taking arthropods, small mammals, birds, amphibians and reptiles (Haug et al. 1993). Seasonal variability in food habits occurs, with vertebrates occurring more commonly in the winter diet and arthropods occurring more frequently in the summer diet (Haug et al. 1993).

Foraging—Burrowing Owls forage in a variety of habitats, including cropland, pasture, prairie dog colonies, fallow fields, and sparsely vegetated areas (Butts and Lewis 1982, Thompson and Anderson 1988, Desmond 1991, Haug et al. 1993, Wellicome 1994). Vegetation >1 m tall may be too tall for Burrowing Owls to locate or catch prey (Haug and Oliphant 1987, 1990; Wellicome 1994).

Productivity—Burrowing Owls are capable of breeding at one year of age. However, some females may not breed the first year after hatching, or may breed away from the natal site the first year after hatching and then return to the natal site in their second year after hatching (Lutz and Plumpton 1999). Second broods have rarely been documented in the Burrowing Owl (Haug et al. 1993). Average clutch size over the range of the species was 6.5 eggs (range 4-12; Haug et al. 1993). In Canada, percent successful reproduction ranged from 45-97% and mean fledging rate ranged from 2.1 to 6.3 young/successful nest (Hjertaas et al. 1995). In British Columbia, 58% (n = 12) of nesting attempts were successful and produced 31 young with a mean brood size of 4.1 ± 1.3 young/successful nest and 2.6 young/attempt (Hjertaas et al. 1995). In Manitoba, average brood size was 5.1 young and overall productivity was 3.4 young/nesting pair (De Smet 1997). In New Mexico, Burrowing Owls produced 3.33 ± 1.49 nestlings and 2.55 ± 1.49 fledglings in human-altered habitats and 1.05 ± 1.23 nestlings and 0.68 ± 0.98 fledglings in natural habitats (Botelho and Arrowood 1996).

Territory—Burrowing Owls generally stay close to the nest burrow during daylight and forage farther from the nest between dusk and dawn (Haug 1985, Haug and Oliphant 1990). Nesting-territory size was 4.8-6.4 ha in Minnesota (n = 2) and 4-6 ha in North Dakota (n = estimated 5-9 pairs) (Grant 1965). Average diurnal ranges of Burrowing Owls in e. Wyoming encompassed 3.5 ha (number of foraging areas not given) (Thompson 1984). Foraging-areas are considerably larger than nesting-areas. In s. Saskatchewan, mean foraging territory size for males ranged from 14 to 481 ha (mean = 241 ha; n = 6) (Haug 1985, Haug and Oliphant 1990). In a heavily cultivated region of s. Saskatchewan, foraging territories for males averaged 35 ha (n = 4) (Sissons et al. 2001).

Aggregations—In nc. Colorado, mean inter-nest distances for Burrowing Owls nesting in black-tailed prairie dog colonies was 101 m (n = 8) (Plumpton 1992). Mean nearest-neighbor distance for Burrowing Owls nesting in 20 American badger excavations in w. Nebraska was 240 m, compared to mean nearest-neighbor distances of 105 m for 118 non-clustered nests in small prairie dog colonies and 125 m for 105 nest clusters in large prairie dog colonies (Desmond 1991, Desmond et al. 1995, Desmond and Savidge 1996). Available excavations may be limiting to Burrowing Owls nesting outside of prairie dog colonies

Within prairie dog colonies, Burrowing Owls have been observed to aggregate their nests into clusters. Mean densities of Burrowing Owls within clusters in larger colonies (≥ 35 ha) were 1.2-1.3 individuals/ha (n = 21). In smaller colonies (<35 ha) with random distributions, mean densities of Burrowing Owls ranged from 1.7 to 5.8 individuals/ha (n = 26). Clustered nest distributions may reduce depredation risks by allowing individuals to alert one another to potential predators (Butts 1973, Desmond 1991, Desmond et al. 1995, Desmond and Savidge 1996).

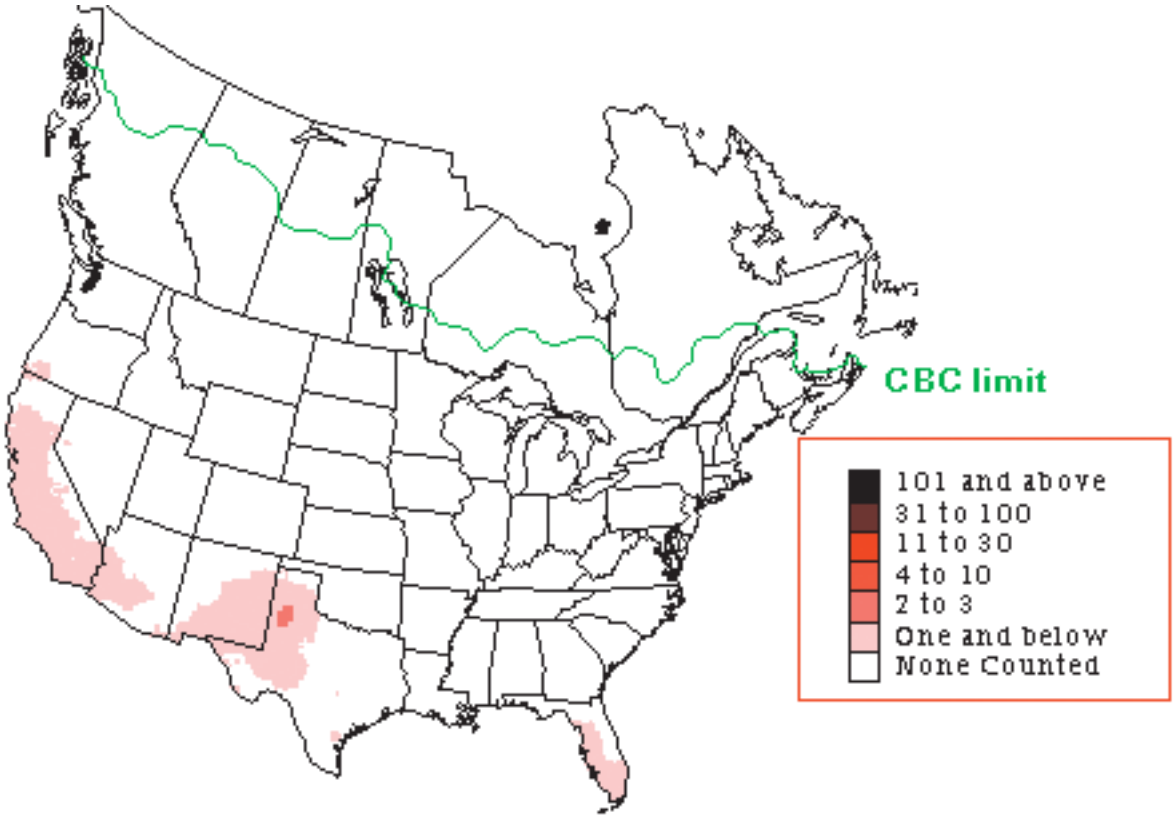

Fig. 3. Winter distribution of Burrowing Owls in the United States from Christmas Bird Count (CBC) data (1966-1989). Shading represents the species relative abundance (birds/100 party hours) averaged for each CBC circle and smoothed over the species distribution (Sauer et al. 1996).

In ne. Colorado, 27 prairie dog colonies with Burrowing Owls ranged in size from 1.9 to 167.6 ha (Hughes 1993). In w. Nebraska, fledging success rates were positively correlated with the size of prairie dog colonies (Desmond 1991).

Mortality and Predation—The annual mortality rate in Oklahoma was estimated at 62% (adults and young combined) (Butts 1973). At two sites in s. Saskatchewan, adult female survival (s) (s = 0.62, n = 12 and s = 1.00, n = 2) was higher than survival for adult males (s = 0.48, n = 11 and s = 0.38, n = 5) or juveniles (s = 0.45, n = 21 and s = 0.48, n = 25) (Clayton and Schmutz 1999).

Predators of Burrowing Owls include badger, domestic cat, weasel, skunk, domestic dog, coyote, Swainson's, Ferruginous, Red-tailed, and Cooper's hawks, Merlin, Prairie, and Peregrine falcons, Great Horned Owl, American Crow (Haug et al. 1993), snakes, bobcats and Northern Harrier (Leupin and Low 2001).

Site and Burrow Fidelity—Individual Burrowing Owls have moderate to high site fidelity to general breeding areas, prairie dog colonies, and even to particular nest burrows. Of 31 adults banded in Colorado in 1990, 39% returned in 1991, whereas only 5% of 369 Burrowing Owls banded as nestlings prior to 1994 returned in one or more years after hatch (Plumpton and Lutz 1993, Lutz and Plumpton 1999). Eight of the remaining 12 returning adults (66%) reused the same prairie dog town as the prior year (Plumpton and Lutz 1993). Adult males and females returned at similar rates (19% and 14%, respectively) (Lutz and Plumpton 1999). Adult males and females nested in formerly used sites at similar rates (75% and 63%, respectively). In Albuquerque, New Mexico, all returning males selected the same burrow they had previously inhabited unless the burrow had been destroyed (n = 9, Martin 1973). In Manitoba, 7% of failed nests (n = 57) were reused in consecutive years but 23% (n = 122) of successful nests were reused (De Smet 1997). Burrow fidelity has been reported in some areas; however, more frequently, Burrowing Owls reuse traditional nesting areas without necessarily using the same burrow (Haug et al. 1993, Dechant et al. 1999). Burrow and nest sites are re-used at a higher rate if the bird has reproduced successfully during the previous year (Haug et al. 1993).

Habitat

Breeding

Burrowing Owl nesting habitat consists of open areas with mammal burrows. They use a wide variety of arid and semi-arid environments, with well-drained, level to gently sloping areas characterized by sparse vegetation and bare ground (Haug et al. 1993, Dechant et al. 1999). Breeding habitats include native prairie, tame pasture, hayland, fallow fields, road and railway rights-of-way, and urban habitats (e.g., campuses, airports, and golf courses) (Dechant et al. 1999). Burrowing Owls do not occupy all apparently available habitat (i.e., prairie dog or ground squirrel colonies). Unused colonies have been documented in virtually all states within the current range of the Burrowing Owl.

Burrowing Owls require a mammal burrow or natural cavity surrounded by sparse vegetation. Burrow availability is often limiting in areas lacking colonial burrowing rodents (Desmond and Savidge 1996). Burrowing Owls frequently use burrows of black-tailed prairie dogs. They nest less commonly in the burrows of Douglas' ground squirrels, white-tailed prairie dogs, Gunnison's prairie dogs, yellow-bellied marmots, woodchucks, skunks, foxes, coyotes, and nine-banded armadillos (Dechant et al. 1999). Where mammal burrows are scarce, Burrowing Owls have been found nesting in natural rock and lava cavities (Gleason 1978, Gleason and Johnson 1985, Rich 1986).

Burrowing Owls may use "satellite" or non-nesting burrows, moving chicks at 10-14 days presumably to reduce risk of predation (Desmond and Savidge 1998) and possibly to avoid nest parasites (Dechant et al. 1999). Successful nests in Nebraska had more active burrows within 75 m of the nest burrow than unsuccessful nests (Desmond and Savidge 1999). Observations made at 15 burrow sites by James and Seabloom (1968) revealed that family units in sw. North Dakota used from one to three satellite burrows, although a few family units used from two to ten satellite burrows. In e. Wyoming, most (actual number not given) nesting areas contained between two and 11 available burrows (Thompson 1984). Three Burrowing Owl families in Iowa used from one to five satellite burrows (Scott 1940). In Oklahoma, black-tailed prairie dog colonies appeared to be the only habitat with a sufficient density of burrows to provide satellite burrows for Burrowing Owls (Butts and Lewis 1982).

Migration

No information is available on migration habitats. They are presumed to be similar to breeding habitats (Haug et al. 1993).

Winter

Little is known about wintering habitat requirements beyond what the species uses during the breeding season, but there seems to be increased use of agricultural fields with culverts in some areas (Haug et al. 1993, W. Howe, pers. commun.). In Louisiana, in winter, Burrowing Owls are typically found in dune vegetation or near woody debris on beaches, in pastures, and in agricultural fields (B. Vermillion, pers. commun.). In sc. Nevada, burrows used in winter were the same as those used during the breeding season (Hall et al. *In review*).

Populations

Population Estimates and Trends

Breeding Bird Survey—The Breeding Bird Survey (BBS) revealed a mixture of population trends throughout the Burrowing Owl breeding range in North America (Table 2, Fig. 4) (Sauer et al. 2002). BBS trends for Burrowing Owls are largely limited by small sample sizes and the species is not adequately sampled over a large part of their breeding range. Trends in nearly all regions are limited by important or potential deficiencies (Sauer et al. 2002). However, when taken as a whole, generally declining populations are present in the northern half of the Great Plains, and generally increasing populations are present in the northwest interior and in some southwestern deserts of the United States (Table 2, Fig. 4).

Christmas Bird Count—Burrowing Owl abundance is poorly monitored by the CBC. Most Burrowing Owls from the Great Plains winter in Mexico where CBC coverage is poor. On the Gulf Coast of Texas, wintering Burrowing Owls are difficult to detect and samples sizes are small. The effort to locate wintering Burrowing Owls has increased in recent years (G. Holroyd, pers. commun.). A significant decreasing trend was observed only in California; trends for other areas were non-significant (Table 3) (Sauer et al. 1996). James and Ethier (1989) detected stable populations in most wintering areas in New Mexico, Louisiana, and Mexico for 1955-85. There were no significant changes in Arizona, New Mexico, Texas, and Louisiana from 1954-86, or in Mexico between 1974 and 1985 (James and Ethier 1989)

Other Surveys, United States—Surveys in California in 1986-91 found population decreases of 23-52% in the number of breeding groups and 12-27% in the number of breeding pairs of owls (DeSante et al. 1997). Populations in w. Nebraska declined 58% (91 to 38 nesting pairs) between 1990-1996 (Desmond and Savidge 1998). Populations in New Mexico have exhibited mixed trends: stable or increasing populations were associated with the presence of suitable habitat and increased precipitation and food availability while decreasing populations were associated with loss of suitable habitat (Arrowood et al. 2001). In Wyoming, only 11% of 86 historical sites were occupied in 1998; however, the importance of this finding is uncertain due to the tendency for Burrowing Owl colonies to move (Korfanta et al. 2001). The Wyoming Game and Fish Department's Wildlife Observation System showed populations generally increasing between 1974-80 and then decreasing between 1981-97 (Korfanta et al. 2001). In North Dakota, Burrowing Owls have disappeared from the eastern third of the state and is uncommon to rare in the best habitats north and east of the Missouri River (Murphy et al. 2001). In sw. North Dakota the current population trend is not clear, but is probably closely tied to populations of prairie dogs (Murphy et al. 2001). Based on questionnaires, literature searches, personal contacts and field observations, Brown (2001) concluded that Burrowing Owls are widespread but uncommon in Arizona. In Oklahoma there are an estimated 800-1000 breeding Burrowing Owls, restricted primarily to the panhandle of the state (Sheffield and Howery 2001). In a survey of National Grasslands, Sidle et al. (2001) found higher occupancy of active prairie dog towns in the southern Great Plains (93%) than in the northern Great Plains (59%).

Table 2. North American Breeding Bird Survey trends, significance level (P), sample size (n) and 95% confidence intervals (CI) for the Burrowing Owl during three different survey periods (Sauer et al. 2002).

	1966–2001					1966–1979			1980–2001		
Area (data credibility)[a]	Trend[b]	P	n	95%	CI	Trend[b]	P	n	Trend[b]	P	n
State/Province											
Alberta (R)	–8.5	0.42	6	–27.2	10.1	51.8	0.26	3	3.9	0.93	3
Arizona (Y)	7.7	0.65	9	–23.8	39.20	—	—	—	–3.1	0.88	8
California (B)	5.9	0.01	32	1.9	9.8	–0.9	0.92	19	5.4	0.03	24
Colorado (Y)	–4.0	0.48	38	–14.9	6.9	–7.8	0.40	9	2.7	0.57	36
Idaho (R)	19.1	0.07	9	1.4	36.8	39.2	0.03	3	28.4	0.06	9
Kansas (Y)	–1.1	0.80	11	–9.1	7.0	10.8	0.34	8	11.7	0.69	8
Montana (R)	–12.6	0.11	10	–26.5	1.3	—	—	—	–14.8	0.19	9
Nebraska (Y)	6.5	0.57	13	–14.9	27.9	33.9	0.11	8	3.8	0.72	8
Nevada (Y)	10.9	0.30	9	–8.2	30.1	0.9	0.97	3	12.1	0.14	6
New Mexico (Y)	0.7	0.85	37	–7.0	8.4	-3.9	0.03	6	2.2	0.77	35
North Dakota (R)	–3.2	0.44	13	–10.9	4.6	19.6	0.15	7	-15.8	0.00	9
Oklahoma (R)	-11.5	0.00	10	-14.1	–8.8	14.2	0.37	6	–4.5	0.34	8
Oregon (Y)	3.8	0.63	11	–11.0	18.5	–14.2	0.66	5	15.5	0.20	8
Saskatchewan (R)	-26.0	0.04	2	-29.3	–22.7	—	—	—	—	—	—
South Dakota (Y)	–7.2	0.16	19	–16.9	2.5	5.2	0.52	14	-11.4	0.08	10
Texas (Y)	–1.9	0.39	28	–6.3	2.4	8.4	0.27	14	–5.2	0.26	24
Utah (Y)	0.9	0.89	14	–11.3	13.0	—	—	—	–6.6	0.14	14
Washington (Y)	–7.8	0.60	7	–35.2	19.7	—	—	—	–19.4	0.20	6
Wyoming (Y)	-23.7	0.04	11	-42.3	–5.2	10.5	0.76	2	5.9	0.53	9
Physiographic strata											
South Texas Brushlands	–3.9	0.46	2	–10.9	3.0	—	—	—	—	—	—
High Plains Border (Y)	5.7	0.45	17	–8.5	19.8	3.1	0.84	11	20.0	0.55	11
High Plains (Y)	–4.0	0.43	50	–14.0	6.0	–1.9	0.85	17	2.4	0.61	46
Drift Prairie (Y)	-26.0	0.01	8	-37.7	–14.3	–13.5	0.40	7	—	—	—

Table 2. Continued

Area (data credibility)[a]	1966–2001					1966–1979			1980–2001		
	Trend[b]	P	n	95%	CI	Trend[b]	P	n	Trend[b]	P	n
Glaciated Missouri Plateau (R)	-11.0	0.04	15	-20.0	–2.0	23.0	0.12	6	–12.8	0.16	10
Great Plain Roughlands (R)	–2.6	0.40	30	–8.6	3.4	16.9	0.03	12	–10.4	0.04	22
Rolling Red Plains (Y)	–0.9	0.77	7	–7.0	5.1	–2.7	0.81	3	1.1	0.75	7
Staked Plains (B)	–2.3	0.39	21	–7.6	2.9	10.3	0.27	10	–4.3	0.38	19
Chihuahuan Desert (Y)	1.8	0.80	22	–12.2	15.8	43.4	0.33	7	–1.1	0.90	20
Great Basin Deserts (Y)	7.3	0.55	8	–15.3	29.9	—	—	—	–1.9	0.83	8
Mexican Highlands (Y)	7.1	0.42	2	–3.6	17.8	—	—	—	–8.1	0.55	2
Sonoran Desert (Y)	6.6	0.03	10	1.6	11.5	–2.6	0.84	5	5.7	0.11	8
Mojave Desert (Y)	–1.4	0.84	6	–14.4	11.6	20.6	0.36	4	–20.2	0.33	4
Wyoming Basin (Y)	-31.0	0.07	4	-53.6	–8.4	10.5	0.76	2	29.0	0.60	2
Intermountain Grassland (Y)	2.8	0.57	27	–6.7	12.3	—	—	—	6.8	0.03	23
Basin and Range (Y)	9.9	0.30	13	–7.8	27.6	0.7	0.96	3	5.8	0.43	10
Columbia Plateau (R)	12.8	0.04	28	1.1	24.4	33.0	0.00	9	21.6	0.01	24
Central Valley (Y)	2.6	0.41	15	–3.3	8.5	–9.6	0.65	9	1.4	0.76	12
USFWS Regions											
Region 1 (Y)	7.1	0.00	68	3.5	10.7	5.7	0.41	31	7.2	0.00	53
Region 2 (Y)	–1.2	0.45	84	–4.4	2.0	–0.5	0.72	29	–1.8	0.63	75
Region 6 (Y)	–4.4	0.29	129	–12.6	3.7	–0.7	0.92	48	–0.2	0.95	103
Country											
Canada (R)	-12.1	0.01	8	-18.4	–5.9	23.8	0.36	4	-18.7	0.02	4
United States (Y)	–1.5	0.57	291	–6.5	3.6	0.0	0.99	113	1.6	0.40	237
Survey-wide (Y)	-1.5	0.57	299	–6.5	3.6	0.2	0.96	117	1.5	0.41	241

[a]–Data credibility measure. (R) = RED: Data with an important deficiency. (Y) = Yellow: Data with a potential deficiency. (B) = BLUE: Data with at least 14 samples in the long term, of moderate precision, and of moderate abundance on routes.

[b]–Mean percent change per year

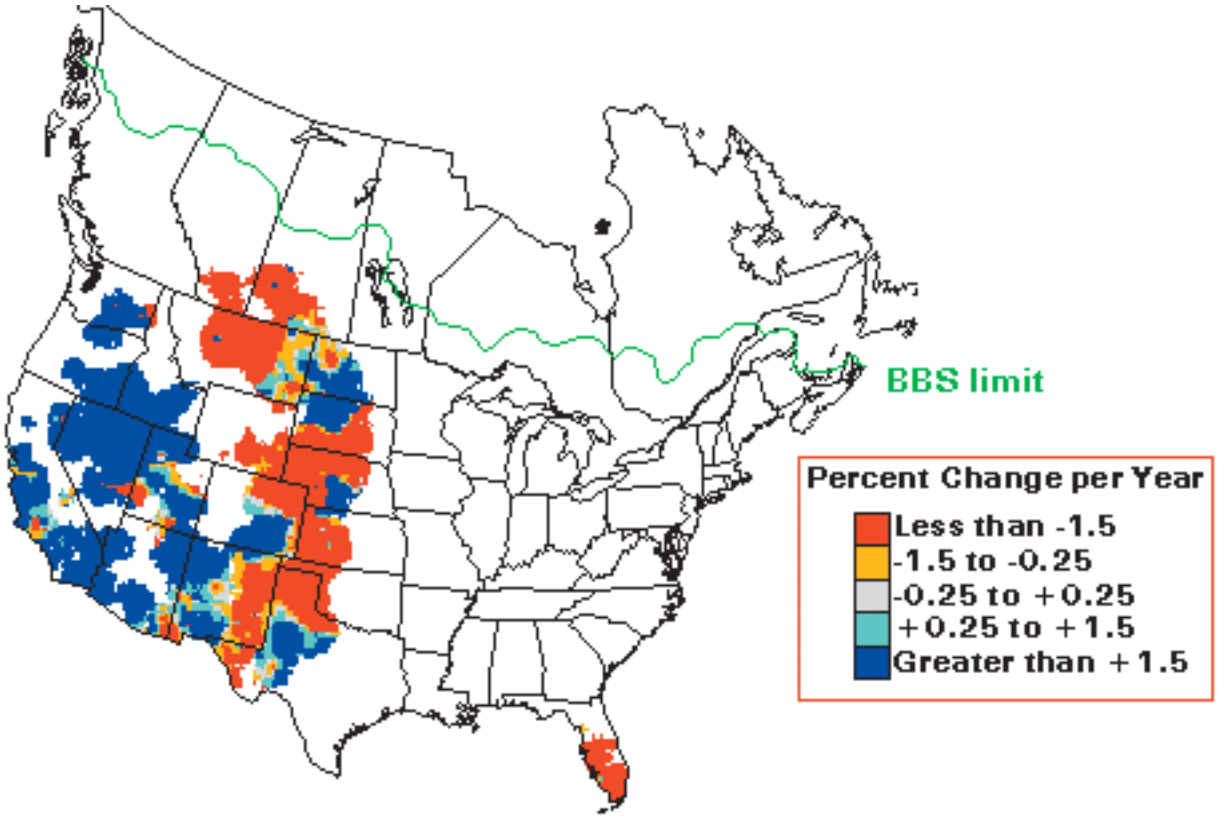

Fig. 4. Breeding Bird Survey trends for Burrowing Owls in the United States and Canada (1966-96, Sauer et al. 2002). These trends do not necessarily reflect statistical significance (see Table 2).

Table 3. Christmas Bird Count trends, sample sizes (n), 95% confidence intervals (CI), significance levels (P), and relative abundance (RA) for the Burrowing Owl in areas with sufficient data for analysis, 1959-1988 (Sauer et al. 1996).

State	Trend[a]	n	95%	CI	P	RA[b]
Arizona	0.2	16	–1.7	2.1	>0.10	0.10
California	–1.2	97	–2.3	–0.1	≤ 0.05	0.29
Texas	1.2	52	–1.3	3.8	>0.10	0.23
Survey-wide	0.2	240	–1.5	1.9	>0.10	0.13

[a]–Mean percent change per year.

[b]–Mean number of birds per 100 party hours.

Field-based, quantitative population estimates do not exist for most states (Table 4). However, James and Espie (1997) submitted surveys to state biologists in 1992 to determine approximate total breeding populations of Burrowing Owls, based on expert opinion and not necessarily based on field investigations of true population levels. Additional population estimates have been made for California, Colorado, Kansas, Montana, and Oklahoma (Table 4).

Other Surveys, Canada—Burrowing Owls declined in Canada from the mid-1970s through at least the early 1990s (Kirk et al. 1994/95) with up to 50% declines in some areas (Dundas and Jensen 1994/95). No complete censuses have been conducted in Canada, but a variety of studies show widespread range contraction and declining density (Hjertaas et al. 1995). Burrowing Owls declined in Alberta, Saskatchewan, and Manitoba at over 20% per year over the past decade (Wellicome and Holroyd 2001). Skeel et al. (2001) documented a 95% decline in Burrowing Owls reported by landowners in Saskatchewan for an average annual decline of 21.5% from 1998-2000. They are effectively extirpated from Manitoba with one pair nesting every second year since 1999 (K. De Smet, pers. commun.). Shyry et al. (2001) reported a significant decrease in the density of Burrowing Owl nests near Hannah, Alberta between 1991 and 2000. The density of nests near Brooks, Alberta did not significantly change from 1991 to 2000.

Based on a survey of biologists, the total breeding population for Canada was estimated as approximately 2,000-20,000 pairs, with the major populations occurring in Alberta and Saskatchewan (Table 4) (James and Espie 1997). In Alberta, the population estimate dropped from 1,500 to 800 birds (47% decline) from 1978-1990 (Wellicome 1997).

Other Surveys, Mexico—Burrowing Owls breed in much of Mexico but the population is unknown. In nw. Chihuahua they occurred on 62% (n = 34) of surveyed prairie dog colonies for a total of 87 owls. Numbers ranged from 0-16 owls/prairie dog colony and 0.00-7.69 owls/ha (VerCauteren et al. *In review*). Two BBS routes in the same area of nw. Chihuahua average 19 and 32 Burrowing Owls per route between 1998 and 2001. As many as 26 adults were visible from a single point on one occasion (W. Howe, pers. commun.).

Densities

In Nebraska, total numbers of Burrowing Owls increased, but density decreased with increasing size of prairie dog towns (Desmond and Savidge 1996). In large (>35 ha) prairie dog towns, distribution was found to be less dense but clumped, and clumping was not related to burrow availability (Desmond et al. 1995). Burrowing Owl density in black-tailed prairie dog colonies was negatively correlated with the density of inactive burrows (Desmond 1991). The density of Burrowing Owls in prairie dog colonies in ne. Colorado was positively related to the percentage of active burrows (Hughes 1993). At least 50% of the burrows were active in 26 of 27 occupied colonies. For prairie dog colonies with over 90% active burrows, mean density was 2.85 owls/ha, and for those with 70-80% active burrows, mean density was 0.57 owls/ha.

Changes in Breeding Season Distribution

United States—The Burrowing Owl has been nearly extirpated from all former breeding range in w. Minnesota, most areas east of the Missouri River in North Dakota, e. Nebraska and Oklahoma, e. and c. Kansas, in large portions of the San Francisco Bay area in California, and in the Rogue Valley in sw. Oregon (DeSante et al. 1997, Martell et al. 2001, Murphy et al. 2001, Sheffield and Howery 2001, Wellicome and Holroyd 2001).

In California, the Burrowing Owl has been extirpated as a breeding species during the last 10-15 years from approximately 8% of its former range (J. Barclay, pers. commun.). They were apparently extirpated as breeding birds during the past decade from Sonoma, Marin, Santa Cruz, and Napa counties, and only one breeding pair apparently still existed in San Mateo County in 1991. The population around the north end of San Francisco, San Pablo, and Suisun Bays was also reduced to a very small remnant. Breeding in central California has been reduced to only three isolated populations: a moderate but declining population of about 720 pairs in the Central Valley; about 143 pairs in the lowlands around the southern arm of San Francisco Bay between Alameda and Redwood City; and a very small, isolated population of about 10 pairs in the Livermore area (DeSante et al. 1997).

In a comparison with historical distributions, Murphy et al. (2001) found that Burrowing Owls were greatly reduced or completely extirpated from nw. and c. North Dakota. Declines in Burrowing Owls may be related to loss of grassland habitat and burrowing rodents in the state (Murphy et al. 2001).

Table 4. Burrowing Owl population estimates for states, provinces, and countries. James and Espie (1997) surveyed state/provincial biologists in 1992 to determine approximate total breeding populations. Other populations estimates are presented only for statewide/province-wide estimates; additional local population estimates can be found in Appendix A: State Summaries of Burrowing Owl Status.

Area	James and Espie (1997)[a]	Other statewide/province-wide estimates (source)
United States	20,000–200,000	
Arizona	100–1,000	None
California	1,000–10,000	9,266 pairs (1991–1993; DeSante et al., unpubl.)
Colorado	1,000–10,000	15,796–20,408 individuals (Hanni 2001)[b]
Idaho	1,000–10,000	None
Iowa	<10	None
Kansas	100–1,000	1,000–10,000 pairs (W. Busby, pers. commun.)
Minnesota	<10	None
Montana	100–1,000	644 + 114 pairs (Atkinson 2000)[c] 300 pairs (Holroyd and Wellicome 1997)
Nebraska	100–1,000	None
Nevada	1,000–10,000	None
New Mexico	1,000–10,000	None
North Dakota	100–1,000	None
Oklahoma	100–1,000	800–1,000 individuals (Sheffield and Howery 2001)
Oregon	1,000–10,000	None
South Dakota	100–1,000	None
Texas	>10,000	None
Utah	1,000–10,000	None
Washington	100–1,000	None
Wyoming	1,000–10,000	None
Canada	2,000–20,000	
Alberta	1,000–10,000	800 birds (in 1990; Wellicome 1997)
British Columbia	<10	<10 pairs (Leupin and Low 2001)
Manitoba	10–100	10–20 pairs (K. De Smet, pers. commun.)
Saskatchewan	1,000–10,000	None
Mexico	Unknown	

[a]–numbers of breeding pairs

[b]–estimates are only for e. Colorado, which represents the majority of breeding habitat in the state.

[c]–estimate is based on surveys of known prairie dog colonies.

In w. Minnesota, Burrowing Owls were considered common in the 1920's; however, significant declines had occurred by the 1960's (Martell et al. 2001). During 1965-1985 only 10 breeding records were recorded. A reintroduction program was attempted from 1986-1990; however no successful nesting has been recorded since 1992.

Canada—The Burrowing Owl has been extirpated from the northern portions of the range in Saskatchewan and Alberta, and all former range in Manitoba and British Columbia (Wellicome 1997, Shyry et al. 2001, Wellicome and Holroyd 2001). Extirpation from all of Canada may occur within a few decades (Wellicome and Haug 1995).

Mexico—Unknown.

Re-occupancy Rates

Of 292 nest burrows that had been occupied in some previous year (1976-83), 39.4% were re-occupied in Idaho in some subsequent year (up to seven years later) (Rich 1984). Burrows in rock outcrops were re-used 48.9% of the time (n = 113) compared to 31.4% (n = 159) for nests in soil mounds. Outcrop sites also were used more often in consecutive years; 23 were used for two years, and 12 were used for three consecutive years. Fifteen mound nests were used for two years, five were used for three years, and one was used four consecutive years. Greater reuse of outcrop sites could be related to their stability as no burrows in outcrops were destroyed. However, nests in old badger burrows were destroyed by plowing, cattle trampling, drifting sand, dredging, and other unknown causes (Rich 1984).

In Colorado, 90% of 18 prairie dog towns and 25% of four nesting burrows were reused between 1990 and 1991 (Plumpton and Lutz 1993). In sc. Idaho in 1994-95, 50% (n = 30) of individual burrows were reused in a subsequent year (Belthoff and King 1997). Of 10 burrows that fledged young in 1994, 70% were reused at least once. Conversely, burrows tended to remain unoccupied in years following nest failures; six nests remained unused in 1995 and 1996 after failing in 1994 (Belthoff and King 1997). In sw. Idaho, low nest reoccupancy was documented (11% from 1991 to 1994, and 42% from 1993 to 1994) (Lehman et al. 1998).

Korfanta et al. (2001) estimated 17% reoccupancy (range: 8-28%) of historic breeding sites in e. Wyoming. The average age of sites reoccupied by Burrowing Owls in 1998 (12.4 years; n = 10) was not significantly different from the average age of all historic observations (13.1 years, n = 86) (Korfanta et al. 2001). In 1999 and 2000, the Rocky Mountain Bird Observatory (RMBO) conducted extensive roadside surveys of potential Burrowing Owl habitat in se. Wyoming. In 1999, they located 71 colonies of Burrowing Owls, totaling 180 individuals (Hutchings et al. 1999). In 2000, they located 107 sites with Burrowing Owls for a total of 575 owls; site reoccupancy was 66% between 1999 and 2000 (T. VerCauteren, pers. commun.).

Monitoring Activities

Range-wide Surveys

There are no ongoing or standardized large-scale monitoring programs that target Burrowing Owls in the United States or Canada other than the BBS and CBC. These surveys do not adequately sample this species throughout its range (Sauer et al. 2002). There are no range-wide monitoring programs in Mexico.

Local Surveys

In Wyoming, Burrowing Owls are voluntarily reported by state and federal biologists, researchers, Audubon Society members, and the general public to the Wyoming Game and Fish Departments (WGFD) Wildlife Observation System (WOS) (Korfanta et al. 2001).

The New Mexico Burrowing Owl Working Group (NMBOWG) has initiated a volunteer monitoring system to collect data on Burrowing Owl populations in the state (C. Finley, pers. commun.).

In e. Colorado, w. Nebraska, w. Kansas, and e. Wyoming, RMBO conducts monitoring of prairie birds, including Burrowing Owls. The objectives are to investigate trends in population and distribution, and to determine local densities of birds (T. VerCauteren, pers. commun.).

Manitoba monitors Burrowing Owl populations through its Threatened Grassland Birds Project (Dundas and Jensen 1994/1995). Monitoring in Saskatchewan and Alberta is conducted through Operation Burrowing Owl (Dundas and Jensen 1994/1995).

Proposed Protocols and Surveys

In California, the California Burrowing Owl Consortium has developed Survey Protocol and Mitigation Guidelines to survey Burrowing Owl populations and to evaluate impacts from development projects. The following web site has the survey protocol and mitigation guidelines (http://www2.ucsc.edu/scpbrg/section1.htm).

In Wyoming, the Arizona Coop. Fish & Wildlife Research Unit conducted standardized population surveys for nesting Burrowing Owls on public lands. The objectives of this project were to determine the factors that influence burrow occupancy, nesting productivity, burrow fidelity, natal recruitment, conduct an annual survival in Wyoming, and to provide a paired comparison between tape and passive surveys in number of birds detected (C. Conway, pers. commun.).

Threats

Habitat: Breeding

Habitat Loss and Fragmentation—Primary threats across the North American range of the Burrowing Owl are habitat loss and fragmentation primarily due to intensive agricultural and urban development, and habitat degradation due to declines in populations of colonial burrowing mammals (Grant 1965, Konrad and Gilmer 1984, Ratcliff 1986, Haug et al. 1993, Dundas and Jensen 1994/95, Rodriguez-Estrella et al. 1998, Sheffield 1997*a*, Dechant et al. 1999). The dramatic reduction of prairie habitat in the United States has been linked to reduction of Burrowing Owl populations (Sheffield 1997*a*).

Fragmentation and isolation may be threats to small and localized populations. Fragmentation of nesting habitat may reduce the opportunity for unpaired owls to find mates (Sheffield 1997*a*). Fragmentation of grassland habitat in Canada has increased the populations of predators that prey on Burrowing Owls (Wellicome and Haug 1995). In contrast, in w. Nebraska landscapes dominated by croplands, Burrowing Owls had higher fledging success (mean of 3.23 fledglings/pair) than owls nesting in rangeland landscapes (mean of 1.49 fledglings/pair) (Desmond 1991). Larger home ranges have been observed in fragmented landscapes (Warnock and James 1997). Higher post-fledging mortality from vehicle collisions occurred in an agricultural landscape with >90% of land area under cultivation compared to an unfragmented rangeland with <20% cultivation (Clayton and Schmutz 1997).

Burrows—Elimination of burrowing rodents through control programs has been identified as the primary factor in the recent and historical decline of Burrowing Owl populations (Butts and Lewis 1982; Pezzolesi 1994; Desmond and Savidge 1996, 1998, 1999; Toombs 1997; Dechant et al. 1999; Desmond et al. 2000; Murphy et al. 2001). Some black-tailed prairie dog colonies have become so isolated through fragmentation that re-population through natural dispersal and colonization is difficult (Benedict et al. 1996). Declines of Burrowing Owl populations in North Dakota north and east of the Missouri River may be related to declines in Richardson's ground squirrel populations (Murphy et al 2001). In w. Nebraska, a 63% decline in Burrowing Owl numbers over a seven year period in 17 black-tailed prairie dog colonies was associated with declines in black-tailed prairie dog densities due to population control activities (Desmond et al. 2000). Burrow habitat in abandoned prairie dog towns becomes unsuitable for Burrowing Owls within one to three years (Butts 1973).

Grazing—Burrowing Owls prefer grasslands moderately or heavily grazed by cattle or prairie dogs (James and Seabloom 1968, Butts 1973, Wedgwood 1976, MacCracken et al. 1985, Bock et al. 1993). The response of Burrowing Owls to cattle grazing is related to the effects of prairie dog grazing and must be evaluated in conjunction with the presence of previously excavated burrows. In sc. Saskatchewan, heavily grazed, poor soils were used frequently by Burrowing Owls, and moderate to heavy grazing on good soils reduced lush vegetative growth and provided suitable habitat (Wedgwood 1976). Burrowing Owls in Saskatchewan and Alberta nested in pastures with shorter vegetation than occurred in randomly chosen pastures, and preferred native or tame pastures over cultivated land (Clayton 1997). In the Oklahoma Panhandle, Butts (1973) suggested that grazing of taller grasses may attract ground squirrels and prairie dogs, thus increasing burrow availability. In North Dakota, Burrowing Owls nested in moderately or heavily grazed mixed-grass pastures, but not in hayed or lightly grazed mixed-grass (Kantrud 1981). Declines in Burrowing Owl populations in North Dakota north and east of the Missouri River may be due to a reduction over the past 20 years in the amount of sheep grazing that occurs in the region (Murphy et al. 2001). In the Platte River Valley of Nebraska, preferred nest sites were in heavily grazed or mowed native grasslands (Faanes and Lingle 1995). Optimal breeding habitat in portions of Colorado, Montana, Nebraska, North Dakota, South Dakota, and Wyoming occurred in heavily grazed areas with aridic ustoll soils and grazed areas with typic boroll soils (Kantrud and Kologiski 1982).

Burning—Little information exists on the response of Burrowing Owls to burning. In nc. Oregon, they were observed nesting in badger excavations in areas that recently had been burned, suggesting that fire may create suitable habitat by reducing vegetation around potential nest sites (Green and Anthony 1989). In nw. North Dakota, post-European settlement fire suppression may be responsible for the development of a taller, denser, and woodier plant community than previously existed (Murphy 1993), and these vegetational shifts may have been responsible for the local extirpation of Burrowing Owls.

Mowing—In nc. Colorado, mowing has been used to control growth of grasses and woody vegetation in areas where black-tailed prairie dogs have been eliminated. Abandoned black-tailed prairie dog colonies that were not mowed were not used by owls (Plumpton 1992). Mowing also may enhance the attractiveness of nest sites for Burrowing Owls returning from the wintering grounds (Plumpton and Lutz 1993). Mowing throughout the breeding season apparently does not adversely affect nesting Burrowing Owls (Dechant et al. 1999).

Habitat: Winter

Threats to Burrowing Owl wintering habitats are largely the same as those to Burrowing Owl breeding habitats; however, documentation and research addressing these threats is much more limited for wintering habitats. VerCauteren et al. (*In review*) reported poisoning of prairie dogs, urban development, and agriculture as the primary threats to prairie dogs and Burrowing Owl habitat in winter. Approximately 50% of the prairie dog colonies resurveyed by VerCauteren et al. (*In review*) were extant, although many of the remaining towns were greatly fragmented.

Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

Not known to be a threat. Burrowing Owls have been trapped and sold in Mexico (G. Holroyd, pers. commun.), although the extent of this practice is unknown.

Predation and Disease

Predation—Cultivation and fragmentation of grassland habitat in Canada have allowed populations of predators that prey on Burrowing Owls to increase (Wellicome and Haug 1995). Burrowing Owls are usually tolerant of human activity but vulnerable to predation by dogs and cats. In Minnesota, high predation rates played a role in the failure of four years of reintroduction efforts (Martell et al. 2001). On Santa Barbara Island, California, a small population of Burrowing Owls (approx. 20) were extirpated by Barn Owls in 1984 and again in 1987 following crashes in the deer mouse population (Drost and McCluskey 1992).

Disease—Not known to be a direct threat (see *Indirect Effects of Disease*, below).

Inadequacy of Existing Regulatory Mechanisms

Burrowing Owls are protected by the Migratory Bird Treaty Act (1918) in the United States and Mexico, which makes it illegal to take, possess, buy, sell, purchase, or barter any migratory bird listed in 50 C.F.R., Part 10. In the United States, the Burrowing Owl was listed as an ESA Category 2 Candidate species until February 1996, when the Category 2 designation was discontinued. Burrowing Owls are listed as Endangered in Canada and as Threatened in Mexico.

Other Natural or Manmade Factors

Disturbance at Nest and Roost Sites—Not known to be a threat.

Ingestion of Plastics, Lead, Etc.—Not known to be a threat.

Collisions with Stationary/Moving Structures—Little information. No Burrowing Owl mortality due to collisions with communication towers was documented (Shire et al. 2000). Burrowing Owls may be susceptible to collisions with vehicles because Burrowing Owls often fly low to the ground. Collisions with vehicles have been cited as a significant source of mortality by several researchers (Haug et al. 1993). Military aircraft have been involved with strikes to Burrowing Owls in e. New Mexico (W. Howe, pers. commun.). Gillihan (2000) documented a Burrowing Owl killed by a collision with a barbed wire fence.

Shooting, Trapping, and Hunting—Illegal shooting may be responsible for substantial mortality in some areas, accounting for 10 of 15 deaths in Oklahoma (Butts 1973). Other studies, however, have not mentioned shooting as a source of mortality (Coulombe 1971, Thomsen 1971, Martin 1973).

Population Size and Isolation—Johnson (1997) reported that a population of Burrowing Owls in California showed a higher genetic similarity than did a collection of geographically separated Burrowing Owl populations. This suggested that some potentially detrimental inbreeding was occurring in the population (Johnson 1997). However, Korfanta (2001) found that populations of Burrowing Owls were genetically indistinguishable, suggesting a high degree of population connectivity and dispersal among populations.

Introduced Species—Not known to be a threat.

Indirect Effects of Disease—Burrowing Owl populations can be negatively impacted, and even eliminated, by epizootics of sylvatic plague that affect prairie dog colonies and thus reduce available habitat for Burrowing Owls (Dechant et al. 1999).

Pesticides and Other Contaminants/Toxics

Based on a survey of biologists, eleven states and provinces reported pesticides as a potential factor in declines (James and Espie 1997). Use of insecticides and rodenticides in Burrowing Owl habitat can be especially detrimental. Pesticides not only reduce the food supply and the number of burrowing mammals, but these chemicals also may be toxic to Burrowing Owls (Ratcliff 1986, James and Fox 1987, James et al. 1990, Baril 1993, PMRA 1995, Hjertaas 1997*a*, Sheffield 1997*b*). Burrowing Owls have been reported to ingest poisoned rodents and to forage on the ground for insects in areas with poison grains also on the ground (Butts 1973, James et al. 1990). In s. Saskatchewan, owls in pastures treated with strychnine-coated grain weighed less than those in control pastures, suggesting a sublethal effect or a reduction in small-rodent prey (James et al. 1990). A breeding population in the Oklahoma Panhandle declined by 71% within one year after sodium fluoroacetate (1080) was applied to the prairie dog colony with nesting owls (Butts 1973). Burrows occasionally are fumigated and sealed in the course of rodent-control programs (Butts 1973). Anti-coagulant rodenticides (e.g., brodifacoum and other second generation [or super-warfarin] compounds) and other types of rodenticides (e.g., strychnine) have been shown to cause mortality in many different owl species, with the ingestion of as few as one poisoned prey item (Sheffield 1997*b*). Burrowing Owls located in proximity to strychnine-coated grain used to control Richardson's ground squirrels were found to have significantly decreased adult body mass and slightly decreased breeding success as compared to control owls (James et al. 1990). Burrowing Owls are known to scavenge dead rodents and other prey items on occasion, making them highly susceptible to secondary poisoning by insecticides and rodenticides (Sheffield 1997*b*).

There have been few studies examining exposure and effects of insecticides on Burrowing Owls; however, available evidence indicates that anti-cholinesterase insecticides can negatively impact Burrowing Owl populations (Sheffield 1997*a*, *b*). In Saskatchewan, reproductive output of Burrowing Owls was not diminished significantly by one or more exposures to carbaryl within 50 or 400 m of the nest burrow; however, spraying of carbofuran within 50 m of the nest burrow caused a 54% reduction in the number of young per nest (James and Fox 1987). When both carbaryl and carbofuran were sprayed within 400 m of the nest, productivity of pairs decreased about 35% more than when carbaryl alone was applied. Direct overspray of carbofuran to the nest burrow resulted in an 83% reduction in brood size and an 82% reduction in nesting success (James and Fox 1987, Fox et al. 1989). Carbofuran application within 50 m of the nest burrow, without direct overspray, resulted in a 17% reduction in brood size and a 27% reduction in nesting success compared with burrows exposed to carbaryl or chloropyrifos. Use of granular formulations of carbofuran is restricted in the United States and Canada (PMRA 1995; L. Cole and P. Mineau, pers. commun.), as is most of its liquid formulations in Canada (PMRA 1995). Liquid carbofuran is still registered for several uses in the United States, and of particular danger to the Burrowing Owls are uses of this chemical in corn and alfalfa fields (Dechant et al. 1999).

Burrowing owl populations in California were sampled for contaminants in the spring of 1996 in the San Joaquin Valley (Lemoore Naval Air Station [NAS]), the Imperial Valley (Sonny Bono Salton Sea National Wildlife Refuge [Salton Sea NWR]), and Carrizo Plain Natural Area (Gervais et al. 2000). Sites were representative of the general agricultural practices in the region; the Carrizo Plain site was a large native grassland. Eggs, blood, feather, and footwash samples were collected from Lemoore NAS and Carrizo Plain, and eggs were collected from Salton Sea NWR. Eggshells from 45 owl nests collected prior to 1937 were obtained from the Western Foundation of Vertebrate Zoology and measured. Eggshell thickness declined 20.58% from Burrowing Owl eggs collected prior to 1937 compared to those collected in 1996. In addition, the eggs from Lemoore NAS were significantly thinner than those from the Salton Sea NWR or Carrizo Plain and contained high concentrations of DDE, ranging from 1.5 to 33 ppm wet weight. Carrizo Plain and Salton Sea NWR eggs contained up to 0.38 and 3.4 ppm DDE, respectively. Feathers from owls nesting at Lemoore NAS also contained levels of DDE, suggesting recent and local exposure. Two Lemoore eggs also contained PCB. Selenium concentrations in eggs were at low concentrations typical of uncontaminated eggs. Footwash samples indicated exposure to the organophosphorus pesticide chlorpyrifos at Lemoore NAS, although no exposure was reported within 1 km of the Burrowing Owl burrows in the months prior to sampling (Gervais et al. 2000). Despite the fact that DDT was banned in 1972, its degradation product DDE clearly remains a threat to wildlife within the San Joaquin Valley. Contaminant loads in these owls also may make them more susceptible to other unrelated stresses, such as weather or exposure to other toxicants (e.g., dicofol), that have similar estrogenic effects as well as thinning effects on eggshells (Gervais et al. 2000).

Recommendation on Current Conservation Status

Data for Western Burrowing Owls in most of the U.S. are insufficient to estimate trends in abundance. Limited data suggest that they are decreasing in some areas, but may be stable or increasing in others. Overall, BBS data (which are reasonably reliable when sample size is adequate) suggest a long-term decline (-1.5%/yr for the U.S.), but this estimate is not statistically significant; the 95% confidence interval for the trend estimate is between –6.5%/yr and +3.6%/yr. Western Burrowing Owls have experienced significant population declines at the northern, western, and eastern fringes of their range, including some local extirpations; however, they continue to occupy the majority of their historical range. Primary threats are habitat loss due to anthropogenic activities, reductions in abundances of burrowing mammals, and contaminants.

Currently, the Western Burrowing Owl is listed by the USFWS as a Bird of Conservation Concern-2002 in most of the BCR's in which it occurs, in every USFWS Region where it occurs, and on the National list (U.S. Fish & Wildlife Service 2002). This designation is intended to stimulate collaborative, proactive conservation actions among public and private land managers and others. Recommended conservation measures include efforts to monitor their demographics and trends more precisely, and to understand the factors affecting their populations during migration and winter. Conservation efforts should focus on protection of suitable habitats in desert, grassland, and shrub-steppe environments. Additional conservation efforts should focus on determining the status of Burrowing Owls in Mexico and on reversing the declines and local extirpations in the Great Plains and Canada. The conservation of burrowing mammals is essential to improve the status of Burrowing Owls, and the listing of the black-tailed prairie dog as a Candidate species should assist in the conservation of both species.

The Migratory Bird Management program of the USFWS recommends retaining the Western Burrowing Owl on the BCC lists on which it currently appears. The listing of the Burrowing Owl as a Bird of Conservation Concern highlights its potential vulnerability and need for increased monitoring and conservation attention by multiple Federal and State agencies and private organizations. The success of these efforts will be reviewed as the Birds of Conservation Concern list is revised.

Management and Conservation

Habitat

Habitat Features—Large, contiguous areas of treeless, native grasslands should be maintained (Warnock 1997, Warnock and James 1997, Clayton and Schmutz 1999). However, because Burrowing Owls forage over tall grass and nest and roost in short grass, a mosaic of grassland habitats are important and a patchwork of reserves with sustainable land uses in nesting and buffer areas is recommended (Clayton and Schmutz 1999). Standardized mitigation protocols to minimize impacts from developments and disturbances should be developed (Holroyd et al. 2001). Government programs and policies that impact Burrowing Owl habitat should be reviewed to ensure that land-use changes have positive effects on Burrowing Owl populations and habitats. Furthermore, management plans for public lands should include issues relative to the conservation of Burrowing Owls, fossorial mammals, and their associated habitats (Holroyd et al. 2001).

The following management recommendations are from the Columbia Basin in Oregon (Green and Anthony 1997): (1) Provide elevated perches near potential nest burrows in grassland areas if the average vegetation height is 5-15 cm; (2) Provide fresh cattle dung near nesting areas if dung is not available and mammalian predators, especially badgers, occur in the area. Burrowing Owls use shredded manure to line their nests and burrow entrances, possibly to mask nest odors as a predator-avoidance strategy (Haug et al. 1993, Dechant et al. 1999). In nc. Oregon, 72% of 32 successful nests were lined with manure, whereas only 13% (n = 15) of depredated nests were lined with manure; (3) Place artificial nest boxes no closer together than 110 m; (4) Construct boxes with width and length dimensions of at least 36 cm and place soil around the inside wall; or construct boxes with only three walls, with a funnel-shaped tunnel entrance; and (5) Select sites for establishing or increasing nest sites that have approximately 55% (40-70%) bare ground and average shrub coverage of <15%.

Fire—Fire may create suitable habitat by reducing vegetation around potential nest sites (Green and Anthony 1989). Post-settlement fire suppression may be responsible for the development of a taller, denser, and woodier plant community than previously existed in North Dakota (Murphy 1993).

Mowing—To encourage Burrowing Owl use in areas where black-tailed prairie dogs and other grazers have been eliminated, mowing may be used to control growth of grasses and woody vegetation. Abandoned black-tailed prairie dog colonies that were not mowed were not used by owls (Plumpton 1992). Mowing also may enhance the attractiveness of nest sites for Burrowing Owls returning from the wintering grounds (Plumpton and Lutz 1993). Mowing throughout the breeding season in mid- to late summer apparently does not adversely affect nesting Burrowing Owls (T. Wellicome, pers. commun.). Mowing can maintain abandoned prairie dog colonies at an early successional stage, with short (<8 cm) vegetation (Plumpton 1992, Plumpton and Lutz 1993). Mowing abandoned colonies may be effective in the short term; however, burrows may require maintenance by prairie dogs to remain suitable for Burrowing Owls (MacCracken et al. 1985, Desmond and Savidge 1999).

Grazing—Livestock grazing may be used to maintain abandoned prairie dog colonies where native burrowing mammals have been eliminated. Heavy grazing on saline, gravelly, stony, or sandy areas and moderate to intense grazing on fertile soils could create suitable habitat that otherwise would support tall vegetation (Wedgwood 1976). However, the effect of grazing on Burrowing Owl habitat and populations is unknown.

Burrowing Mammals

Conservation of those species of burrowing mammals that form Burrowing Owl nest sites is essential for maintaining populations of Burrowing Owls. Some populations of black-tailed prairie dogs are in danger of local extirpation, and their colonies may have become so isolated that re-population through natural dispersal and colonization is unlikely (Benedict et al. 1996). Fragmentation and isolation of habitat patches are potentially important factors in the decline of black-tailed prairie dog populations (Dechant et al. 1999). Burrows may require maintenance by prairie dogs in order to ensure their long-term suitability for owls and it may be necessary to release prairie dogs into inactive colonies (MacCracken et al. 1985, Desmond et al. 2000). Holroyd et al. (2001) suggested the expansion of prairie dog colonies on public lands, and the development of economic incentives to make it profitable to maintain prairie dog populations on private lands.

Regulation of poisoning and shooting of prairie dogs, particularly on public lands, may be necessary (Benedict et al. 1996, Toombs 1997). If lethal control of burrowing mammals is necessary, restricting the timing of control activities to avoid the period when Burrowing Owls choose nest sites or are nesting is recommended (Butts 1973). Traps, poisoned meat, or poisoned grain should not be used for rodent control, but rather burrows unoccupied by owls should be fumigated (Butts 1973, Thomson 1988). However, fumigation may have negative impacts on other burrow dependent species. The area of prairie dog colonies should be increased, possibly by reintroducing prairie dogs where they have been eliminated or by releasing additional prairie dogs into active colonies to promote colony expansion (Pezzolesi 1994, Toombs 1997). It is particularly important to protect colonies ≥ 35 ha in area, which provide adequate space for nesting Burrowing Owls (Desmond et al. 1995, Dechant et al. 1999).

Reintroduction and Relocation

Reintroduction—Reintroduction programs have been attempted in British Columbia, Manitoba, Minnesota, and Oklahoma with no success. In British Columbia, an ongoing captive breeding program reared and released over 140 Burrowing Owls between 1992 and 1998. Released birds have raised broods, overwintered at release sites, and migrated south in winter, but few have returned to the release site in spring (Leupin and Low 2001, Munro et al. 1984). In Manitoba, reintroductions between 1986 and 1996 used a variety of methods, including the aid of aviaries and artificial burrows, but resulted in low reproduction and poor return rates and reintroductions were discontinued (De Smet 1997). In Minnesota, 105 juveniles were released in a reintroduction program over four years, but no successful breeding occurred and the program was discontinued (Haug et al. 1993, Martell et al. 2001). Holroyd et al. (2001) recommended a review of Burrowing Owl reintroduction techniques and development of new techniques due to failure of previously used methods.

Relocations and Artificial Burrows—Relocations are those in which Burrowing Owls are evicted from their occupied burrows and artificial burrows are constructed as near to the eviction burrows as possible to provide acceptable unoccupied burrows for their use. Ninety percent (n = 6) of artificial burrows in California were immediately occupied and these burrows supported successfully breeding birds for three consecutive years (Trulio 1995). Artificial burrows were used when they were approximately 50-100 m from the burrow (Thomsen 1971, Haug and Oliphant 1990). Artificial burrows more than 100 m from the eviction burrow may greatly reduce the chances that new burrows will be used.

The rates of survival and reproduction of Burrowing Owls relocated to artificial burrows as well as the long-term use of artificial burrows and the ability of these burrows to maintain populations are unknown. The design and installation of artificial nest burrows should be summarized and the conservation value of this practice determined (Holroyd et al. 2001). Follow-up research needs to be conducted to determine the breeding success of relocated Burrowing Owls (Holroyd et al. 2001).

Pesticide Use

If insect control is necessary, insecticides with the lowest toxicity to nontarget organisms should be used (James and Fox 1987, Fox et al. 1989). Municipal governments and agricultural representatives should be encouraged to reduce or restrict the use of pesticides, and to use pesticides of low toxicity to nontarget species (Thomson 1988). Pesticides should not be sprayed within 400-600 m of Burrowing Owl nest burrows during the breeding season (Haug 1985, Haug and Oliphant 1990, James and Fox 1987). The possible negative effects of pesticides on Burrowing Owl populations should be considered on breeding and wintering grounds (Holroyd et al. 2001).

Monitoring

A standardized, range-wide survey for Burrowing Owls should be developed and implemented. Potential survey protocols should be tested to ensure the quantitative validity of the methodology (Holroyd et al. 2001). Most current monitoring programs have problems due to limited coverage or sample size (see Monitoring Activities, above). A standardized range-wide roadside survey using call playback has been recommended. This method was 80% effective at detecting Burrowing Owls using a 15 minute period (five minutes listening, five minutes call playback, five minutes listening periods), in early morning and in the early breeding season (Duxbury and Holroyd 1998). The use of recorded calls can significantly increase Burrowing Owl detections, particularly males (Haug and Didiuk 1993). Both historical sites and areas previously unoccupied by owls should be monitored. Because of low nest reoccupancy rates for Burrowing Owls, long-term monitoring of abundance should not be based solely on surveys of historical breeding sites (Lehman et al. 1998).

Migration

Little information is available. Research projects conducted by Saskatchewan Environment and Resource Management and the Canadian Wildlife Service have attempted to relocate radio-transmittered Burrowing Owl on their wintering grounds. Burrowing Owls marked during the breeding season in Canada (Saskatchewan and Alberta) have been relocated in s. Texas and c. Mexico (Veracruz and Michoacan states). Tagged Burrowing Owls were capable of migrating 200 km per night, taking at least 2-3 weeks to move from breeding to wintering grounds. It is estimated that Burrowing Owls take 6-8 weeks to move from wintering to breeding grounds (http://www.serm.gov.sk.ca/ecosystem/speciesatrisk/burrowingowl.htm, http://members.aol.com/joemoell/owl2.html, G. Holroyd, pers. commun.).

Wintering Areas

Very little information is available. Although the general wintering range of Burrowing Owls is known, very little is known about habitats used during the winter (Holroyd et al. 2001). Conservation of Burrowing Owls may depend on acquiring knowledge about the wintering areas and about movement patterns, timing, and ecology during migration and winter. Very few studies have been carried out in Mexico, Central America, or South America. The rapid population decline in Canadian provinces, despite apparent availability of suitable habitat, suggests unknown factors in winter and migration may be affecting survival or return rates (Schmutz 1997).

Education

Private landowners and the general public should be educated about the status of Burrowing Owls, the benefits of protecting habitat for the species and for burrowing mammals, and the negative effects of insecticides (Butts 1973, James and Fox 1987, Thomson 1988, Hjertaas 1993, Dechant et al. 1999, Holroyd et al. 2001). Stewardship of Burrowing Owls and their habitat should be encouraged on public land in the United States, Canada, and Mexico (Holroyd et al. 2001). An educational program should be developed for schools and outdoor education programs, and the media should be included in these activities (Thomson 1988, Holroyd et al. 2001). A project to improve the public image of prairie dogs should be undertaken (Benedict et al. 1996, Holroyd et al. 2001). Operation Burrowing Owl (a private stewardship program in Canada) has been extremely successful at obtaining landowner cooperation in conservation efforts, and has provided valuable population trend data for Burrowing Owls in Canada (Hjertaas 1997*b*). RMBO and Hawks Aloft, Inc. have also developed successful education and public participation programs.

Current Activities and Programs

United States—In California, the Burrowing Owl Consortium, an *ad hoc* group of biologists and advocates, meets two times a year. The Consortium members inform each other and the public of important issues related to the species, and subcommittees of the Consortium undertake projects designed to help the species (L. Trulio, pers. commun.). The California Burrowing Owl Consortium prepared the *Burrowing Owl Survey Protocol and Mitigation Guidelines* in 1993 to provide more consistent treatment of impacts to Burrowing Owls during development projects. This document was submitted to the California Department of Fish and Game and became the basis of their 1995 *Staff Report on Burrowing Owl Mitigation* (California Department of Fish and Game, unpubl. report).

RMBO manages "Prairie Partners", a program that requests voluntary cooperation from private landowners to conserve shortgrass prairie birds and their habitat through effective stewardship (Hutchings et al. 1999). In 1999, "Prairie Partners" documented 468 Burrowing Owl locations (79.3% on public land). Information is provided to landowners about shortgrass prairie conservation and Burrowing Owl natural history. The program also provides information about landowner attitudes toward Burrowing Owls and prairie dogs.

RMBO also published "Sharing Your Land with Shortgrass Prairie Birds" (Gillihan et al. 2001) which includes a section on Burrowing Owl identification, natural history, and habitat requirements and a booklet focusing on grasslands and grassland birds for elementary and secondary classroom use (Hutchings et al. 1999). These materials are being distributed to landowners, managers, and schools.

The New Mexico Burrowing Owl Working Group (NMBOWG) was formed in response to population declines at some sites in New Mexico (Hawks Aloft, Inc. 2002). The NMBOWG is an volunteer, collaborative effort of non-profit organizations, government agencies, private enterprises and individuals. The working group attempts to encourage communication, support research, and facilitate improved Burrowing Owl sighting accuracy and reporting. The NMBOWG currently supports on-going research projects at four sites: Holloman and Kirtland Air Force Bases, New Mexico State University, and the Turner Ranch. The NMBOWG has initiated a volunteer monitoring system to collect data on Burrowing Owl populations in the state (C. Finley, pers. commun., Hawks Aloft, Inc. 2002).

Canada—Operation Burrowing Owl is a program designed to address declines of Burrowing Owls in Saskatchewan and Alberta. Activities include increasing public awareness, placing nest boxes, encouraging voluntary land protection, and providing monetary incentives to landowners to protect nesting habitat and avoid pesticide use around nest sites (Hjertaas 1997*b*). As of 1993, several hundred landowners were enrolled in the project and were protecting over 20,000 ha of breeding habitat, which supported several hundred breeding pairs (Dundas and Jensen 1994/95).

Through the Critical Wildlife Habitat Program, Threatened Grassland Birds Project in Manitoba, nearly 3,500 ha of critical habitat have been leased or voluntarily protected for Burrowing Owls and other grassland species, and over 300 artificial nest burrows have been installed (Dundas and Jensen 1994/95).

The Canadian Burrowing Owl Recovery Team was formed in 1989 to coordinate and promote research and conservation activities to prevent the decline of this species in Canada. This team meets annually to review information and to develop and implement recovery plans. The British Columbia recovery team has attempted to reintroduce Burrowing Owls into that province for over a decade. In Alberta, a provincial recovery team was formed in 2001 to develop and implement a provincial action plan. Several organizations conduct public education programs to increase awareness of Burrowing Owl conservation issues. The Saskatchewan Burrowing Owl Interpretive Centre in Moose Jaw was specifically established to promote awareness of Burrowing Owl conservation both to visitors and through extensive school extension programs. The Alberta Fish and Game Association through their Operation Grassland Community delivers similar programs in the province. The Canadian Species at Risk Habitat Stewardship Program funds non-government partners to deliver habitat stewardship projects in all four western provinces which benefit Burrowing Owls, their habitats and other prairie wildlife. (G. Holroyd, pers. commun.).

Research Needs

Coordinated, range-wide research on population demographics needs to be conducted to determine causes of populations declines (Holroyd and Wellicome 1997, Holroyd et al. 2001). Metapopulation dynamics, influence of landscape patterns, and the effects of fragmentation and isolation on populations are not well understood. Basic distribution data and factors affecting survival during migration and on wintering grounds are poorly known and may be important in determining causes of population declines (Holroyd et al. 2001). A standardized survey to monitor population trends in Canada, the U.S., and Mexico is recommended as many population estimates are simply based on "best guesses" and current large-scale monitoring programs are largely inadequate (Holroyd et al. 2001).

Management strategies currently in use need to be evaluated for their effectiveness and the resulting information made easily available to managers. Further investigations also are needed on land use impacts, prescribed fire, grazing, mowing, habitat enhancements (e.g., artificial burrows and perches), relocation and reintroduction, and impact of predators on nest success (Millsap et al. 1997, Sheffield 1997*a*, Holroyd et al. 2001). Rates of habitat conversion and degradation (e.g., agricultural conversion or decline in burrowing mammal colonies) are rarely reported and more work is needed to determine rate and extent of habitat loss (James and Espie 1997). Modeling of Burrowing Owl habitat selection has been suggested to better understand the role of anthropogenic factors in population declines (Holroyd et al. 2001).

Although some research exists on carbofuran, studies of many other pesticides are also needed (James and Espie 1997, Holroyd et al. 2001). Indirect and sublethal effects of pesticides are largely unknown. The extent of mortality and vulnerability to shooting, particularly during prairie dog and ground squirrel control, is generally unknown.

Some education programs have already been successfully developed and implemented. However, additional research is needed to determine landowner and land manager attitudes to Burrowing Owls and burrowing mammals and to determine best methods for improving attitudes and conservation efforts on private and public lands.

Literature Cited

An extensive bibliography of articles pertaining to the Burrowing Owl was compiled by L. Ayers. The bibliography is available on the internet at the following address: http://uwadmnweb.uwyo.edu/fish_wild/buow/citations.html

American Ornithologists' Union. 1998. Check-list of North American Birds. Seventh Edition. American Ornithologists' Union, Washington, DC.

Arrowood, P. C., C. A. Finley, and B. C. Thompson. 2001. Analyses of Burrowing Owl populations in New Mexico. Journal of Raptor Research 35:362-370.

Baril, A. 1993. Pesticides and wildlife in the prairies: current regulatory issues. Pages 44-48 *in* G. L. Holroyd, H. L. Dickson, M. Regnier, and H. C. Smith, editors. Proceedings of the third endangered species and prairie conservation workshop. Natural History Occasional Paper 19. Provincial Museum of Alberta, Edmonton, Alberta, Canada.

Belthoff, J. R. and B. A. King. 1997. Between-year movements and nest burrow use by Burrowing Owls in southwestern Idaho. Technical Bulletin No. 97-3, Idaho Bureau of Land Management.

Benedict, R. A., P. W. Freeman, and H. H. Genoways. 1996. Prairie legacies—mammals. Pages 149-167 *in* F. B. Samson and F. L. Knopf, editors. Prairie conservation: preserving North America's most endangered ecosystem. Island Press, Covelo, California.

Bock, C. E., V. A. Saab, T. D. Rich, and D. S. Dobkin. 1993. Effects of livestock grazing on Neotropical migratory landbirds in western North America. Pages 296-309 *in* D. M. Finch and P. W. Stangel, editors. Status and management of Neotropical migratory birds. U.S.D.A. Forest Service, General Technical Report RM-229.

Botelho, E. S., and P. C. Arrowood. 1996. Nesting success of western Burrowing Owls in natural and human-altered environments. Pages 61-68 *in* D. Bird, D. Varland, and J. Negro, editors. Raptors in human landscapes: Adaptation to Built and Cultivated Environments. Academic Press, Inc.

Brown, N. L. 2001. The howdy owls of Arizona: a review of the status of *Athene cunicularia*. Journal of Raptor Research 35:344-350.

Butts, K. O. 1973. Life history and habitat requirements of Burrowing Owls in western Oklahoma. M.S. Thesis. Oklahoma State University, Stillwater, Oklahoma.

Butts, K. O., and J. C. Lewis. 1982. The importance of prairie dog towns to Burrowing Owls in Oklahoma. Proceedings of the Oklahoma Academy of Science 62:46-52.

Clark, R. J., J. L. Lincer, and J. S. Clark. 1997. Appendix A: a bibliography on the Burrowing Owl (*Speotyto cunicularia*). Pages 145-170 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Clayton, K. M. 1997. Post-fledging ecology of Burrowing Owls in Alberta and Saskatchewan: dispersal, survival, habitat use, and diet. M.S. Thesis. University of Saskatchewan, Saskatoon, Saskatchewan, Canada.

Clayton, K. M., and J. F. Schmutz. 1997. Burrowing Owl (*Speotyto cunicularia*) survival in prairie Canada. Pages 107-110 *in* J. R. Duncan, D. H. Johnson, and T. H. Nicholls, editors. Biology and conservation of owls of the Northern Hemisphere. U.S.D.A. Forest Service, General Technical Report NC-190. North Central Forest Experiment Station, St. Paul, Minnesota.

Clayton, K. M., and J. K. Schmutz. 1999. Is the decline of Burrowing Owls *Speotyto cunicularia* in prairie Canada linked to changes in Great Plains ecosystems? Bird Conservation International 9:163-185.

Coulombe, H. N. 1971. Behavior and population ecology of the Burrowing Owl, *Speotyto cunicularia*, in the Imperial Valley of California. Condor 73:162-176.

De Smet, K. D. 1997. Burrowing Owl (*Speotyto cunicularia*) monitoring and management activities in Manitoba, 1987-1996. Pages 123-130 *in* J. R. Duncan, D. H. Johnson, and T. H. Nicholls, editors. Biology and conservation of owls of the Northern Hemisphere: Second International Symposium. U.S.D.A., Forest Service General Technical Report NC-190, North Central Forest Experiment Station, St. Paul, Minnesota.

Dechant, J. A., M. L. Sondreal, D. H. Johnson, L. D. Igl, C. M. Goldade, P. A. Rabie, and B. R. Euliss. 1999. Effects of management practices on grassland birds: Burrowing Owl. Northern Prairie Wildlife Research Center, Jamestown, North Dakota. Northern Prairie Wildlife Research Center Home Page. http://www.npwrc.usgs.gov/resource/literatr/grasbird/buow/buow.htm

DeSante, D.F. and E. Ruhlen. 1995. A census of Burrowing Owls in California, 1991-1993. Institute for Bird Populations, Point Reyes Station, California.

DeSante, D. F., E. D. Ruhlen, S. L. Adamany, K. M. Butron, and S. Amin. 1997. A census of Burrowing Owls in central California in 1991. Pages 38-48 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Desmond, M. J. 1991. Ecological aspects of Burrowing Owl nesting strategies in the Nebraska panhandle. M.S. Thesis. University of Nebraska, Lincoln, Nebraska.

Desmond, M. J., and J. A. Savidge. 1996. Factors influencing Burrowing Owl (*Speotyto cunicularia*) nest densities and numbers in western Nebraska. American Midland Naturalist 136:143-148.

Desmond, M. J., and J. A. Savidge. 1998. Burrowing Owl conservation in the Great Plains. Page 9 *in* Abstracts of the Second International Burrowing Owl Symposium, Ogden, Utah.

Desmond, M. J., and J. A. Savidge. 1999. Satellite burrow use by Burrowing Owl chicks and its influence on nest fate. *In* P. D. Vickery and J. R. Herkert, editors. Ecology and conservation of grassland birds in the western hemisphere. Studies in Avian Biology 19.

Desmond, M. J., J. A. Savidge, and K. M. Eskridge. 2000. Correlations between Burrowing Owl and black-tailed prairie dog declines: a 7-year analysis. Journal of Wildlife Management 64:1067-1075.

Desmond, M. J., J. A. Savidge, and T. F. Seibert. 1995. Spatial patterns of Burrowing Owl (*Speotyto cunicularia*) nests within black-tailed prairie dog (*Cynomys ludovicianus*) towns. Canadian Journal of Zoology 73:1375-1379.

Drost, C. A., and R. C. McCluskey. 1992. Extirpation of alternative prey during a small rodent crash. Oecologia 92:301-304.

Dundas, H., and J. Jensen. 1994/95. Burrowing Owl status and conservation. Bird Trends 4:21-22.

Duxbury, J. M., and G. L. Holroyd. 1998. Testing a possible standardized, road-side survey technique for Burrowing Owls. Abstract and notes. Second International Burrowing Owl Symposium, Ogden, Utah.

Enriquez-Rocha, P. L. 1997. Seasonal Records of the Burrowing Owl in Mexico. 1997. Pages 49-51 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Faanes, C. A., and G. R. Lingle. 1995. Breeding birds of the Platte River Valley of Nebraska. Northern Prairie Wildlife Research Center home page, Jamestown, North Dakota. http://www.npwrc.usgs.gov/resource/distr/birds/platte/platte.htm (Version 16JUL97).

Fox, G. A., P. Mineau, B. Collins, and P. C. James. 1989. The impact of the insecticide carbofuran (Furadan 480F) on the Burrowing Owl in Canada. Technical Report Series No. 72. Canadian Wildlife Service, Ottawa, Canada.

Gervais J. A., D. K. Rosenberg, D. M. Fry, L. J. Trulio, and K. K. Sturm. 2000. Burrowing owls and agricultural pesticides: evaluation of residues and risks for three populations in California, USA. Environmental Toxicology and Chemistry 19:337-343.

Gillihan, S. W. 2000. Barbed wire fence fatal to Burrowing Owl. Journal of the Colorado Field Ornithologists 34:220-221.

Gillihan, S. W., D. J. Hanni, S. W. Hutchings, T. Toombs, and T. VerCauteren. 2001. Sharing your land with shortgrass prairie birds. Unpublished Report. Rocky Mountain Bird Observatory, Brighton, Colorado.

Gleason, R. S. 1978. Aspects of the breeding biology of Burrowing Owls in southeastern Idaho. M.S. Thesis. University of Idaho, Moscow, Idaho.

Gleason, R. S., and D. R. Johnson. 1985. Factors influencing nesting success of Burrowing Owls in southeastern Idaho. Great Basin Naturalist 45:81-84.

Grant, R. A. 1965. The Burrowing Owl in Minnesota. Loon 37:2-17.

Green, G. A., and R. G. Anthony. 1989. Nesting success and habitat relationships of Burrowing Owls in the Columbia Basin, Oregon. Condor 91:347-354.

Green, G. A., and R. G. Anthony. 1997. Ecological considerations for management of breeding Burrowing Owls in the Columbia Basin. Pages 117-121 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Symposium. Raptor Research Report Number 9.

Hall, D. B., P. D. Greger, and A. V. Housewright. *In review.* Burrowing owl ecology on the Nevada Test Sites. DOE/NV/11718–701. U.D. Department of Energy, National Nuclear Security Administration Nevada Operations Office, Las Vegas, Nevada.

Hanni, D. J. 2001. Comparison of four methodologies used to monitor shortgrass prairie birds in eastern Colorado. Unpublished Report. Rocky Mountain Bird Observatory, Brighton, Colorado.

Haug, E. A. 1985. Observations on the breeding ecology of Burrowing Owls in Saskatchewan. M.S. Thesis. University of Saskatchewan, Saskatoon, Saskatchewan.

Haug, E. A., and A. B. Didiuk. 1991. Updated status report on the Burrowing Owl, *Athene cunicularia hypugaea*, in Canada. Committee on the Status of Endangered Wildlife in Canada.

Haug, E. A., and A. B. Didiuk. 1993. Use of recorded calls to detect Burrowing Owls. Journal of Field Ornithology 64:188-194.

Haug, E. A., and L. W. Oliphant. 1990. Movements, activity patterns, and habitat use of Burrowing Owls in Saskatchewan. Journal of Wildlife Management 54:27-35.

Haug, E. A., B. A. Millsap, and M. S. Martell. 1993. Burrowing Owl (*Speotyto cunicularia*). *In* A. Poole and F. Gill, editors. The birds of North America, No. 61. The Academy of Natural Sciences, Philadelphia, Pennsylvania; The American Ornithologists' Union, Washington, DC.

Hawks Aloft, Inc. 2002. New Mexico Burrowing Owl Working Group web page. http://www.hawksaloft.org/burrowingowl.html.

Hjertaas, D. 1993. The Burrowing Owl recovery program. Pages 350-352 *in* G. L. Holroyd, H. L. Dickson, M. Regnier, and H. C. Smith, editors. Proceedings of the Third Endangered Species and Prairie Conservation Workshop. Natural History Occasional Paper 19. Provincial Museum of Alberta, Edmonton, Alberta.

Hjertaas, D. G. 1997*a*. Recovery plan for the Burrowing Owl in Canada. Pages 107-111 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Hjertaas, D. G. 1997*b*. Operation Burrowing Owl in Saskatchewan. Pages 112-116 *in* J. L. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Hjertaas, D., S. Brechtel, K. De Smet, O. Dyer, E. Haug, G. Holroyd, P. James, and J. Schmutz. 1995. National recovery plan for the Burrowing Owl. Report No. 13. Recovery of Nationally Endangered Wildlife Committee. Ottawa, Canada.

Holroyd., G. L., and T. I. Wellicome. 1997. Report on the Burrowing Owl (*Speotyto cunicularia*) conservation workshop. Pages 612-615 *in* J. R. Duncan, D. H. Johnson, and T. H. Nicholls, editors. Biology and conservation of owls of the Northern Hemisphere. U.S.D.A. Forest Service, General Technical Report NC-190. North Central Forest Experiment Station, St. Paul, Minnesota.

Holroyd, G. L., R. Rodriguez-Estrella, and S. R. Sheffield. 2001. Conservation of the Burrowing Owl in western North American: issues, challenges, and recommendations. Journal of Raptor Research 35:399-407.

Hughes, A. J. 1993. Breeding density and habitat preference of the Burrowing Owl in northeastern Colorado. M.S. Thesis. Colorado State University, Fort Collins, Colorado.

Hutchings, S., M. Carter, E. Atkinson, T. VerCauteren, C. Finley, S. Gillihan, and J. Nocedal. 1999. Prairie Partners: promoting stewardship of shortgrass prairie. Unpublished Report, Colorado Bird Observatory, Brighton, Colorado.

Illinois Natural History Information Network. 2000. Illinois birds: Burrowing Owl (*Athene cunicularia*). Illinois Natural History Survey webpage. Http://www.inhs.uiuc.edu/chf/pub/ifwis/birds/index.html (version August, 2000).

James, D. A., and J. C. Neal. 1986. Arkansas Birds: their distribution and abundance. University of Arkansas Press, Fayetteville, Arkansas.

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: an agency survey. Pages 3-5 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

James, P. C. and T. J. Ethier. 1989. Trends in the winter distribution and abundance of Burrowing Owls in North America. American Birds 43:1224-1225.

James, P. C., and G. A. Fox. 1987. Effects of some insecticides on productivity of Burrowing Owls. Blue Jay 45:65-71.

James, P. C., G A. Fox, and T. J. Ethier. 1990. Is the operational use of strychnine to control ground squirrels detrimental to Burrowing Owls? Journal of Raptor Research 24:120-123.

James, T. R., and R. W. Seabloom. 1968. Notes on the burrow ecology and food habits of the Burrowing Owl in southwestern North Dakota. Blue Jay 26:83-84.

Johnson, B. S. 1997. Demography and population dynamics of the Burrowing Owl. Pages 28-33 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Kantrud, H. A. 1981. Grazing intensity effects on the breeding avifauna of North Dakota native grasslands. Canadian Field-Naturalist 95:404-417.

Kantrud, H. A., and R. L. Kologiski. 1982. Effects of soils and grazing on breeding birds of uncultivated upland grasslands of the northern Great Plains. U.S. Fish and Wildlife Service, Wildlife Research Report 15.

Kirk, D. A., D. Hussell, and E. Dunn. 1994/95. Raptor population status and trends in Canada. Bird Trends 4:2-9.

Konrad, P. M., and D. S. Gilmer. 1984. Observations on the nesting ecology of Burrowing Owls in central North Dakota. Prairie Naturalist 16:129-130.

Korfanta, N. M. 2001. Population genetics of migratory and resident Burrowing Owls (*Athene cunicularia*) elucidated by microsatellite DNA markers. M.S. Thesis. University of Wyoming, Laramie, WY.

Korfanta, N. M., L. W. Ayers, S. H. Anderson, and D. B. McDonald. 2001. A preliminary assessment of Burrowing Owl status in Wyoming. Journal of Raptor Research 35 :337-343.

Lehman, R. N., L. B. Carpenter, K. Steenhof, and M. N. Kochert. 1998. Assessing relative abundance and reproductive success of shrubsteppe raptors. Journal of Field Ornithology 69:244-256.

Leupin, E. E. and D. J. Low. 2001. Burrowing Owl reintroduction efforts in the Thompson-Nicola region of British Columbia. Journal of Raptor Research 35:392-398.

Lutz, R. S., and D. L. Plumpton. 1999. Philopatry and nest site reuse by Burrowing Owls: implications for productivity. Journal of Raptor Research 33:149-153.

MacCracken, J. G., D. W. Uresk, and R. M. Hansen. 1985. Vegetation and soils of Burrowing Owl nest sites in Conata Basin, South Dakota. Condor 87:152-154.

Martell, M., H. B. Tordoff, and P. T. Redig. 1994. The introduction of three native raptors into the Midwestern United States. Raptor Conservation Today: 465-470.

Martell, M. S., J. Schladweiler, and F. Cuthbert. 2001. Status and attempted reintroduction of Burrowing Owls in Minnesota, USA. Journal of Raptor Research 35:331-336.

Martin, D. J. 1973. Selected aspects of Burrowing Owl ecology and behavior. Condor 75:446-456.

Millsap, B. A. 1996. Florida Burrowing Owl. Pages 579-587 *in* J. A. Rodgers, Jr., H. W. Kale II, and H. T. Smith, editors. Rare and Endangered Biota of Florida, Vol V. Birds. University Press of Florida, Gainesville, Florida.

Millsap, B. A, M. I. Bellocq, and M. Mullenix. 1997. Overview of the literature on the Burrowing Owl. Pages 6-10 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Munro, W. T., R. C. Lincoln, and R. W. Ritcey. 1984. Reestablishing Burrowing Owls—experiences in British Columbia. Proceedings of the Western Association of Fish and Wildlife Agencies 64:165-170.

Murphy, R. K. 1993. History, nesting biology, and predation ecology of raptors in the Missouri Coteau of northwestern North Dakota. Ph.D. dissertation. Montana State University, Bozeman, Montana.

Murphy, R. K., D. W. Hasselblad, C. D. Grondahl, J. G. Sidle, R. E. Martin, and D. W. Freed. 2001. Status of the Burrowing Owl in North Dakota. Journal of Raptor Research 35:322–330.

NatureServe Explorer: An Online Encyclopedia of Life. 2001. Version 1.6. Arlington, Virginia. Http://www.natureserve.org/explorer.

Pezzolesi, L. S. W. 1994. The western Burrowing Owl: increasing prairie dog abundance, foraging theory, and nest site fidelity. M.S. Thesis. Texas Tech University, Lubbock, Texas.

Plumpton, D. L. 1992. Aspects of nest site selection and habitat use by Burrowing Owls at the Rocky Mountain Arsenal, Colorado. M.S. Thesis. Texas Technical University, Lubbock, Texas.

Plumpton, D. L., and R. S. Lutz. 1993. Nesting habitat use by Burrowing Owls in Colorado. Journal of Raptor Research 27:175-179.

Pest Management Regulatory Agency (PMRA). 1995. Carbofuran. Decision Document E95-05. Pest Management Regulatory Agency, Health Canada, Ottawa, Ontario, Canada.

Ratcliff, B. D. 1986. The Manitoba Burrowing Owl survey, 1982-1984. Blue Jay 44:31-37.

Restani, M., L. R. Rau, and D. L. Flath. 2001. Nesting ecology of Burrowing Owls occupying prairie dog towns in southeastern Montana. Journal of Raptor Research 35:296-303.

Rich, T. 1984. Monitoring Burrowing Owl populations: implications of burrow re-use. Wildlife Society Bulletin 12:178-180.

Rich, T. 1986. Habitat and nest-site selection by Burrowing Owls in the sagebrush steppe of Idaho. Journal of Wildlife Management 50:548-555.

Rodriguez-Estrella, R., F. Chavez Ramirez, and G. L. Holroyd. 1998. Current knowledge of the Burrowing Owl in Mexico: what is needed for a conservation plan? Abstract and notes. Second International Burrowing Owl Symposium, Ogden, Utah.

Sauer, J. R., J. E. Hines, and J. Fallon. 2001. The North American Breeding Bird Survey Results and Analysis 1966-2000. Version 2001.2. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey Results and Analysis 1966-2001. Version 2002.1. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

Sauer, J. R., S. Schwartz, and B. Hoover. 1996. The Christmas Bird Count Home Page. Version 95.1 U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr.nbs.gov/bbs/cbc.html.

Schmutz, J. K. 1997. Selected microhabitat variables near nests of Burrowing Owls compared to unoccupied sites in Alberta. Pages 80-83 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Scott, T. G. 1940. The Western Burrowing Owl in Clay County, Iowa, in 1938. American Midland Naturalist 24:585-593.

Sheffield, S. R. 1997*a*. Current status, distribution, and conservation of the Burrowing Owl (*Speotyto cunicularia*) in Midwestern North America. Pages 399-407 *in* J. R. Duncan, D. H. Johnson, and T. H. Nicholls, editors. Biology and conservation of owls of the Northern Hemisphere. U.S.D.A. Forest Service, General Technical Report NC-190. North Central Forest Experiment Station, St. Paul, Minnesota.

Sheffield, S. R. 1997*b*. Owls as biomonitors of environmental health hazards. Pages 383-398 *in* Biology and conservation of owls of the North Hemisphere. USDA Forest Service, General Technical Report NC-190.

Sheffield, S. R. and M. Howery. 2001. Current status, distribution, and conservation of the Burrowing Owl in Oklahoma. Journal of Raptor Research 35:351-356.

Shire, G. G., K. Brown, and G. Winegard. 2000. Communication towers: A deadly hazard to birds. American Bird Conservancy, Washington, DC.

Shyry, D. T., T. I. Wellicome, J. K. Schmutz, G. L. Erickson, D. L. Scobie, R. F. Russell, and R. G. Martin. 2001. Burrowing Owl population-trend surveys in southern Alberta: 1991-2000. Journal of Raptor Research 35:310-315.

Sidle, J. G., M. Ball, T. Byer, J. J. Chynoweth, G. Foli, R. Hodorff, G. Moravek, R. Peterson, and D. N. Svingen. 2001. Occurrence of Burrowing Owls in black-tailed prairie dog colonies on Great Plains National Grasslands. Journal of Raptor Research 35:316-321.

Sissons, R., K. Scalise, and T. I. Wellicome. 2001. Nocturnal foraging habitat use of the Burrowing Owl in a heavily cultivated region of southern Saskatchewan. Journal of Raptor Research 35:304–309.

Skeel, M. A., J. Keith, and C. S. Palaschuk. 2001. A population decline recorded by Operation Burrowing Owl in Saskatchewan. Journal of Raptor Research 35:371-377.

Thompson, C. D. 1984. Selected aspects of Burrowing Owl ecology in central Wyoming. M.S. Thesis. University of Wyoming, Laramie, Wyoming.

Thompson, C. D. and S. H. Anderson. 1988. Foraging behavior and food habits of Burrowing Owl in Wyoming. Prairie Naturalist 20:23-28.

Thomsen, L. 1971. Behavior and ecology of Burrowing Owls on the Oakland Municipal Airport. Condor 73:177-192.

Thomson, K. A. 1988. Management of Burrowing Owls in Manitoba, population distribution and plan for recovery. M.S. Thesis. Natural Resource Institute, University of Manitoba, Winnipeg, Manitoba.

Toombs, T. P. 1997. Burrowing Owl nest-site selection in relation to soil texture and prairie dog colony attributes. M.S. Thesis. Colorado State University, Fort Collins, Colorado.

Trulio, L. A. 1995. Passive relocation: a method to preserve Burrowing Owls on disturbed sites. Journal of Field Ornithology 66:99-106.

U.S. Fish & Wildlife Service. 2002. Birds of Conservation Concern. U.S. Department of the Interior, Fish and Wildlife Service, Administrative Report, Arlington, Virginia. http://migratorybirds.fws.gov/reports/bcc2002.pdf.

VerCauteren, T. L., S. W. Gillihan, and S. W. Hutchings. 2001. Distribution of Burrowing Owls on public and private lands in Colorado. Journal of Raptor Research 35:357-361.

VerCauteren, T. L., D. J. Hanni, and S. Hutchings. *In review*. Occurrence of Burrowing Owls on black-tailed prairie dog colonies in northern Mexico during the winter. Journal of Raptor Research.

Warnock, R. G. 1997. Spatial, temporal and turnover dynamics of Burrowing Owl (*Speotyto cunicularia*) distribution in the extensively fragmented grasslands of Saskatchewan. M.S. Thesis, University of Regina, Regina, Saskatchewan.

Warnock, R. G., and P. C. James. 1997. Habitat fragmentation and Burrowing Owls (*Speotyto cunicularia*) in Saskatchewan. *In* J. R. Duncan, D. H. Johnson, and T. H. Nicholls, editors. Biology and conservation of owls of the Northern Hemisphere: Second International Symposium. U.S.D.A., Forest Service General Technical Report NC-190, North Central Forest Experiment Station, St. Paul, Minnesota.

Wedgwood, J. A. 1976. Burrowing Owl in south-central Saskatchewan. Blue Jay 34:26-44.

Wedgwood, J. A., 1978. The status of the Burrowing Owl in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, Ontario.

Wedgwood, J. A. 1979. Status report on the Burrowing Owl, *Athene cunicularia*. Committee on the Status of Endangered Wildlife in Canada.

Wellicome, T. I. 1994. Taverner award recipient's report: Is reproduction in Burrowing Owls limited by food supply? Picoides 7:9-10.

Wellicome, T. I. 1997. Status of the Burrowing Owl (*Speotyto cunicularia hypugaea*) in Alberta. Wildlife Status Report No. 11. Alberta Environmental Protection, Wildlife Management Division, Edmonton, Alberta.

Wellicome, T. I., and E. A. Haug. 1995. Second update of status report on the Burrowing Owl (*Speotyto cunicularia*) in Canada. Committee on the Status of Endangered Wildlife in Canada, Canadian Wildlife Service, Environment Canada, Ottawa, Ontario.

Wellicome, T. I., and G. L. Holroyd. 2001. The Second International Burrowing Owl Symposium: background and context. Journal of Raptor Research 35:269-273.

Zarn, M. 1974. Habitat management series for unique or endangered species. U.S. Department of Interior, Bureau of Land Management, Technical Note T/N-250 (no. 11), Denver, Colorado.

Appendix A: State Summaries of Burrowing Owl Status

Arizona

Summary: Combining historical and recent records, Burrowing Owls have been documented (breeding and/or wintering) in 14 of 15 counties (all except Greenlee County, Fig. A-1) (Brown 2001). A family group was observed in the San Rafael Valley, Santa Cruz County in 2002 (J. Ruth, pers. commun.). Although not present in the early 1900's along the lower Colorado River, Burrowing Owls are now common there, suggesting that agriculture may have benefitted the species in that region (Rosenberg et al. 1991, Brown 2001). However, the vegetation maintenance regime of farming and water districts may cause these populations to remain unstable due to unreliable and temporary habitats (Brown 2001). Main concentrations in the Tucson area are located at Davis-Monthan Air Force Base (DMAFB) and along the west branch of the Santa Cruz River (Estabrook and Mannan 1998).

Statewide Burrowing Owls populations appear to be relatively stable to slightly decreasing (T. Corman, pers. commun.); however, no quantitative information has been gathered on Burrowing Owls since Phillips et al. (1964; Brown 2001). Some local populations are decreasing, especially in urban and agricultural areas, and some populations have been extirpated (Brown 2001).

Status determination in the sw. United States in 1979 and 1988 was precluded by insufficient information (Johnson et al. 1979, Johnson-Duncan et al. 1988). A preliminary review of Burrowing Owls in Arizona was conducted in 1998, through extensive literature reviews, questionnaires, requests for observations, and personal observations (Brown 2001). A formal status could not be given due to the lack of quantitative information on this species in Arizona. Through survey responses, state biologists estimated 100 to 1,000 pairs in 1992 (James and Espie 1997).

BBS: No significant trends were detected over any survey periods (Sauer et al. 2002).

CBC: No significant trend was detected over the survey period (Sauer et al. 1996).

Atlas: Based on preliminary information collected by the Arizona Breeding Bird Atlas (Arizona Breeding Bird Atlas, Unpubl. data, 1993-2001, C. Wise, pers. commun.), the overall breeding range in Arizona has not changed substantially in the 1990's. Burrowing Owls were reported in 78 (4%) of 1825 BBA blocks (Fig A-1, T. Corman, pers. commun).

Research/Monitoring: The Urban Raptor Nest Watch Program of the Arizona Game and Fish Department (c. Arizona) recorded six nests for the Phoenix Metro Area in 1994, three in 1995, and five or six in 1996 (F. Esparza, pers. commun.). Estabrook and Mannan's (1998) urban study found 77 active breeding burrows in the Tucson area in 1997; 28 of these were on DMAFB and the majority of the others were on the west branch of the Santa Cruz River. The number of active burrows appeared to remain stable year-round on DMAFB and fairly stable in the Santa Cruz River flood plain; the vegetation maintenance regime along the flood plain often destroys active burrows (Estabrook and Mannan 1998).

Conservation Activities: Artificial burrows have been placed in some urban areas of the greater Phoenix area (T. Corman, pers. commun.). Artificial burrows have also been constructed at Cibola National Wildlife Refuge along the Lower Colorado River.

Major Populations: A major population occurs at the Davis-Monthan Air Force Base and west branch Santa Cruz River flood plain near Tucson. Unconfirmed high numbers of Burrowing Owls have been reported along the irrigation canals around the Yuma area. Burrowing Owls have been reported from a variety of other areas throughout Arizona; however, no quantitative information has been documented other than in the Tucson region (Estabrook and Mannan 1998).

State Status: None

Natural Heritage Rank: G4/S3 (rare and uncommon in the state)

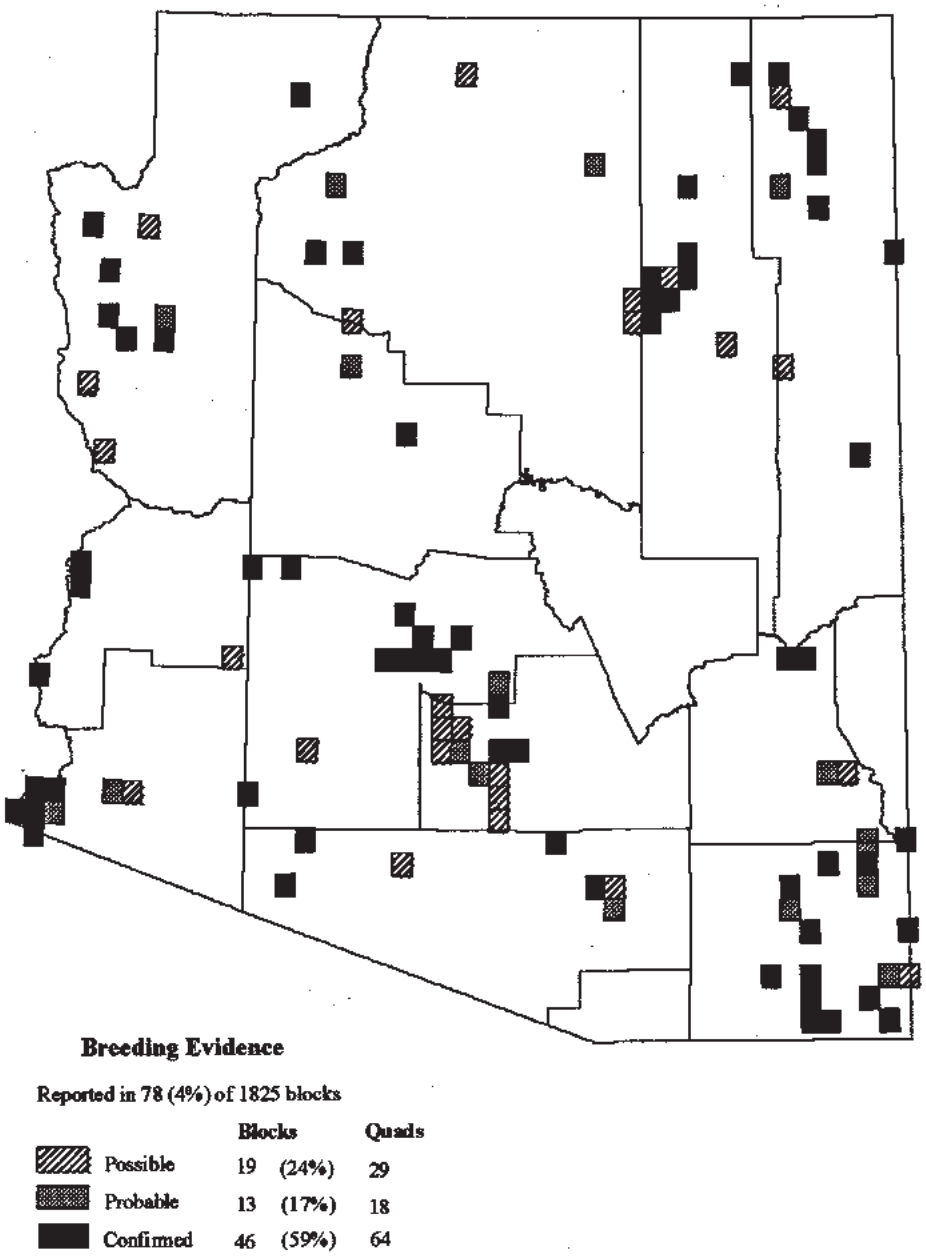

Fig. A-1. Distribution of the Burrowing Owl in Arizona from the Arizona Breeding Bird Atlas project (Arizona Breeding Bird Atlas, Unpubl. data (1993-2001), C. Wise, pers. commun.)

Habitat Condition: Arizona BBA activities located Burrowing Owls in the following habitat types: semi-desert grassland, plains grassland, cropland, Great Basin desert-scrub, lower Colorado River biome of the Sonoran Desert-scrub, barren ground, Great Basin grassland, Arizona upland biome of Sonoran Desert-scrub, Mojave Desert-scrub, rural, and residential (Brown 2001). From survey data, Brown (2001) indicated they also use parks (golf courses, cemeteries), cultivated woodlands (orchards, tree farms) and airports (including Air Force bases).

Burrowing Owls inhabit grass, forb, and open shrub stages of pinyon pine and ponderosa pine habitats (Carothers et al. 1973, Karlaus and Eckert 1974, Zenier et al. 1990). Other areas in Arizona where the owls might be found include washes, irrigation canals, near water tanks or corrals on rangelands, and in vacant lots, and other disturbed sites in urban and rural areas (Rosenberg et al. 1991, Witzeman 1997, deVos 1998, Brown 2001). Occasionally they are found in sandy, sparsely vegetated riparian woodlands in the Lower Colorado River Valley (Rosenberg et al. 1991).

Burrowing Owls are predominately associated with prairie dog towns and round-tailed ground squirrel populations (deVos 1998, Latta et al. 1999, Brown 2001). Both of these burrowing mammals usually inhabit open environments and provide burrows and short vegetation (Hoffmeister 1986, deVos 1998).

Shrub encroachment by mesquite in se. Arizona has eliminated extensive tracts of grassland habitat for the Burrowing Owl (Brandt 1951). In n. Arizona, Burrowing Owls formerly inhabited Anita and Pasture Washes in the Grand Canyon region, but the habitat is now unsuitable due to shrub encroachment (Brown 2001). Such habitat change has been due to grazing practices and prairie dog control programs (Brandt 1951, Brown 2001).

Threats: The Arizona Partners in Flight Bird Conservation Plan (Latta et. al 1999) lists the following threats: 1) Reduction of prairie dogs and ground squirrels through control programs and plague events indirectly limit habitats available to Burrowing Owls; 2) Urban and agricultural development directly reduces available habitat; 3) Urbanization also increases the risk of contraction of Trichomoniasis from doves (Estabrook and Mannan 1998); and 4) increased mortality from vehicles, humans, and domestic and feral animals.

Literature Cited:

Arizona Breeding Bird Atlas. Unpubl. Data. 1993-1999. Arizona Game and Fish Department, Nongame Branch, Phoenix, Arizona.

Brandt, H. 1951. Arizona and its bird life. The Bird Research Foundation, Cleveland, OH.

Brown, N. L. 2001. The Howdy Owls of Arizona: A review of the status of *Athene cunicularia*. Journal of Raptor Research 35:344-350.

Carothers, S. W, J. R. Haldeman, and R. P. Balda. 1973. Breeding birds of the San Francisco Mountain Area and the White Mountains. Tech. Series. No. 12. Northern Arizona Soc. of Science and Art, Inc. Flagstaff, Arizona.

deVos, J. C., Jr. 1998. Burrowing Owl (*Athene cunicularia*). Pp 166-169 *in* R. L. Glinski, editor. The Raptors of Arizona. University of Arizona Press, Tucson, AZ and Arizona Game and Fish Department., Phoenix, Arizona.

Estabrook, T. S., and R. W. Mannan. 1998. Urban habitat selection by Burrowing Owls; Final Report. Heritage Grant U96006; Arizona Game and Fish Department, Phoenix, Arizona.

Hoffmeister, D. F. 1986. Mammals of Arizona. Univ. of Arizona Press, Tucson, Arizona and Arizona Game and Fish Department, Phoenix, Arizona.

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: an agency survey. Pages 3-5 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Johnson, R. R., L. T. Haight, and J. M. Simpson. 1979. Owl populations and species status in the southwestern United States. *in* P. P. Schaeffer, and S. M. Ehlers, editors. Proceedings of the National Audubon Society's Symposium on the Owls of the West: their Ecology and Conservation, Tiburon, California.

Johnson-Duncan, E. E., D. K. Duncan, and R. R. Johnson. 1988. Small nesting raptors as indicators of change in the southwest desert. Pp 232-236 *in* Glinksi, Pendelton, Moss, LeFranc, Millsap, and Hoffman, editors. Proceedings of the Southwest Raptor National Wildlife Federation Scientific and Technical Series No. 11. Washington, DC.

Karlaus, K. E., and A. W. Eckert. 1974. The owls of North America. Doubleday, Garden City, New York.

Latta, M. J., C. J. Beardmore, and T. E. Corman. 1999. Arizona Partners in Flight Bird Conservation Plan. Version 1.0. Nongame and Endangered Wildlife Program Technical Report 142. Arizona Game and Fish Department, Phoenix, Arizona.

Phillips, A. R, J. T. Marshall, and G. Monson. 1964. The Birds of Arizona. University of Arizona Press, Tucson, Arizona.

Rosenberg, K. V., R. D. Ohmart, W. C. Hunter, and B. W. Anderson. 1991. Birds of the Lower Colorado River Valley. University of Arizona Press, Tucson, Arizona.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966–2001. Version 2002.1. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

Sauer, J. R., S. Schwartz, and B. Hoover. 1996. The Christmas Bird Count Home Page. Version 95.1. Patuxent Wildlife Research Center, Laurel, Maryland.

Zeiner, D. C., W. F. Laudenslayer, Jr., K. Mayer, and M. White, editors. 1990. California's Wildlife, Volume 11: Birds. The Resources Agency, Sacramento, California.

Witzeman, J. L., S. R. Demaree, and E.L. Radke. 1997. Birds of Phoenix and Maricopa county, Arizona. Maricopa Audubon Society.

Additional Author For Arizona State Summary:

Nikolle L. Brown, 7779 N. Leonard, Clovis, California 93611

California

Summary: California supports one of the largest year-round (resident) and winter (migrant) populations of Burrowing Owls within the United States. The distribution of Burrowing Owls has changed considerably since introduction of industrial agriculture and increased urbanization, reflecting both losses and gains in local populations. Surveys conducted during 1991-93 reported >9,000 breeding pairs. Most Burrowing Owls occurred within the Central (24%) and Imperial Valleys (71%), primarily in agricultural areas. Burrowing Owls have disappeared or declined in several southern California and San Francisco Bay counties and in coastal areas. Without increased regulatory protection of habitat, Burrowing Owls will likely be extirpated in some areas. However, the large and widespread current population and the Burrowing Owl's high reproductive performance in disturbed environments suggests that the California population is not under immediate or foreseeable threat. Changes in agricultural practices, particularly regarding water conveyance, and urbanization have the potential to quickly affect California's Burrowing Owl population. Evaluation of the ability of large publicly managed lands to support Burrowing Owl populations is important to assess the Burrowing Owl's viability in California.

BBS: Significant increases in relative abundance in California over the 1966-2001 survey period (Trend = 5.5, $P < 0.01$, n = 32) and the 1980-2001 subinterval (Trend = 5.0, $P < 0.05$, n = 24). Data credibility is good indicating adequate sample size, moderate precision, and moderate abundance on routes (Sauer et al. 2002).

CBC: Significant decreasing trends in Burrowing Owl relative abundance were detected from 1959-88 (Trend = –1.2, $P < 0.05$, n = 97) (Sauer et al. 1996).

Atlas: Several counties have atlases, but no single state atlas is available.

Research/Monitoring: Historical accounts indicated that the Burrowing Owl was widely distributed and relatively common in California grasslands (Canfield 1869, Dawson 1923, Grinnell and Miller 1944). Numbers during winters were reported to have declined between 1954-1986 (James and Ethier 1989). Additional declines were reported from the San Francisco Bay area, where development has reduced the amount of Burrowing Owl habitat (DeSante et al. unpubl. ms, Trulio 1997). Johnson (1997) reported a rapid decline in numbers of nesting Burrowing Owls on a 370-acre study site on the University of California Davis campus (Yolo Co.).

The Institute for Bird Populations conducted a volunteer-based survey in 1991-1993 within most of the range of Burrowing Owls in California (DeSante et al. 1997, DeSante et al. unpubl. ms.). They estimated over 9,000 breeding pairs of Burrowing Owls in California (Fig. A-1). Most Burrowing Owls found during the survey were in agricultural areas although it was likely that higher numbers exist in large grasslands than revealed through the surveys (DeSante et al. *In press*). Based on comparisons of survey results and observations made during the early 1980s, DeSante et al. (unpubl. ms.) reported that Burrowing Owls were extirpated during the last 10-15 years from several areas in California, including Napa, Marin, San Francisco, Santa Cruz, and Ventura counties, and coastal San Luis Obispo county and Coachella Valley. Few individuals were observed in Sonoma, Santa Barbara, Orange, coastal Monterey, and San Mateo counties. Most of these areas maintained few Burrowing Owls prior to reported declines; occasional observations of Burrowing Owls nesting in some of these counties have been reported recently (D. DeSante, pers. commun.). The most apparent decline of Burrowing Owls was reported from the Bay area, where DeSante et al. (1997) estimated an approximately 50% decline in Burrowing Owl numbers from the 1980s to the early 1990s.

A multi-site demographic study was initiated in 1997 and coordinated through The Institute for Bird Populations, Oregon State University, and San Jose State University. The study included four sites by 1998, representing the primary habitats in which most of California's Burrowing Owl populations exist. This included South San Francisco Bay ("Bay Area") representing urban environments, Naval Air Station Lemoore ("Lemoore") representing small grassland patches surrounded by agriculture, Carrizo Plain National Monument ("Carrizo"), representing large grasslands, and the Imperial Valley, representing intensive agriculture with nests restricted to field borders. Preliminary results from this study (Rosenberg et al., unpubl. data) demonstrate variability in density and demographic performance among sites (Table A-1).

The number of pairs/ha within the entire study area was similar among sites except for Imperial Valley, which had densities approx. 8 times that of all other sites (Table A-1). By contrast, the number of pairs/ha of potential nest habitat, varied dramatically. Survival rates of Burrowing Owls captured as adults were similar among sites, with Imperial Valley having the highest rates (Table A-1), although there was high temporal variation that was site-specific (Rosenberg et al., unpubl. data). Mortality was high at Carrizo, with predation by other raptors identified as the single largest cause (Rosier et al., unpubl. ms). Reproductive rates, estimated as the number of 21-28 day-old young (Gorman et al., unpubl. ms.), varied among sites (Table A-1), but temporal variation within sites was greater. Temporal variation was apparently related to the abundance of vertebrate prey (Haley 2002, Gervais 2002, Ronan 2002). Reproductive rates were highest in the two agricultural sites, Lemoore and Imperial Valley. Nest failure was largely responsible for differences among the four sites.

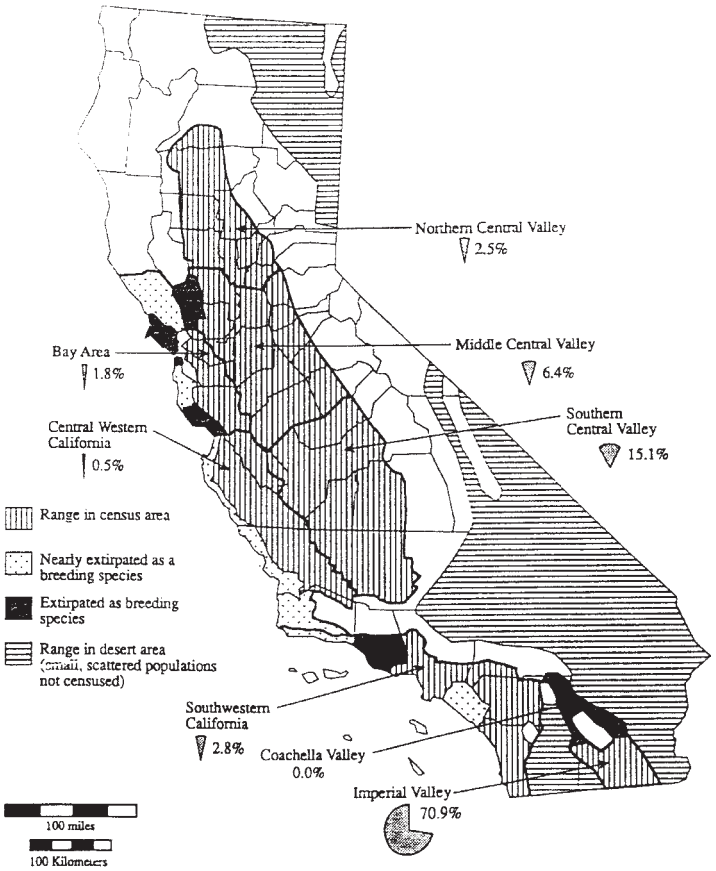

Fig. A-2. Distribution of Burrowing Owl Populations in California, 1991-1993 (9,266 breeding pairs, estimate) (DeSante et al. unpubl. ms.).

For Burrowing Owls, estimates of juvenile survival rates have rarely been reported (but see Gervais 2002), due in part to the difficulty of separating survival from emigration. If one assumes that survival is lower for juveniles than adults (i.e., <0.5, Table A-1), then stability is most likely to occur only when reproductive rates are >2 young/nest (Table A-2). This reproductive rate was achieved or exceeded at each site in some years.

Densities, survival rates, and reproductive rates of Burrowing Owls were high in a wide range of modified habitat conditions. These demographic characteristics were highest in agricultural areas (Lemoore and Imperial Valley) and similar between the urban area of southern San Francisco Bay and the grasslands of Carrizo. If we assume that Carrizo's population growth rate over the long-term is close to stable, then the modified environments of agriculture and urban landscapes (given the conditions at the time of the study) seem likely to provide habitat for stable populations of Burrowing Owls based on the preliminary results from the demographic study. The documented long-term decline in the San Francisco Bay Area is due to nest habitat loss. Further work determining densities of Burrowing Owls in large grasslands, survival rates of juvenile Burrowing Owls, and dispersal patterns of both juveniles and adults will be required for a better understanding of the long-term viability of Burrowing Owls in California. These analyses are now underway for the California demographic studies reported here.

Conservation Activities: The Burrowing Owl Consortium, an ad hoc group of Burrowing Owl biologists and advocates in the San Francisco Bay prepared the *"Burrowing Owl Survey Protocol and Mitigation Guidelines"* in 1993 (California Burrowing Owl Consortium 1997), the basis of California Department of Fish and Game's (1995) *"Staff Report on Burrowing Owl Mitigation."* Repeated conflicts between Burrowing Owls and development projects have lead some municipalities and larger-scale planning boards to consider preparing Burrowing Owl habitat conservation programs for their respective jurisdictions.

In an effort to better inform the public, a brochure and two videos on the Burrowing Owl in California were prepared by The Institute for Bird Populations and Oregon State University. These have been distributed at no charge to federal and state natural resource agencies, visitor centers at locations with Burrowing Owls, and to elementary and high schools.

Table A-1. Comparison of mean density, survival, and reproductive rates of Burrowing Owls at four sites in California.

Site	Years of Study	Area (km^2)	Pairs observed	Crude Density[a]	Ecological Density[b]	Survival[c]	No. Young[d]
Bay Area	98-01	60 (estimate)	64	1.1	5.2	0.55	1.6/3.1
Lemoore	97-00	76.1	67	0.9	15.2	0.44	2.8/3.8
Carrizo	97-00	183.5	38.9	1.0	1.0	0.23/0.61	1.9/4.0
Imperial Valley	98-01	11.8	99	8.3	145.6	0.60	2.1/2.9

[a] Number of estimated pairs/km^2.

[b] Number of estimated pairs/km^2 of potential nest habitat. A width of 20 m was used along canals and drains to estimate the area of nest habitat within the Imperial Valley.

[c] Apparent annual survival rates are based on the single best average estimate with years and sex pooled. At Carrizo, survival rate was estimated as an annual interval from mark-recapture data (0.23) and from radio-telemetry data (0.61) over a 3 month interval during the breeding season. The mark-recapture estimate from Carrizo is negatively biased due to high breeding dispersal (Rosier et al., umpubl. ms.). Apparent survival is an estimate of survival under the assumption that emigration from the study area does not exist.

[d] Number of young reported are, first, the average number for all nests assessed, and, second, the number at successful nests. Estimates are based on counts during 5, 30-min observation (Gorman et al, unpubl. ms.; Rosenberg and Haley *In press*).

Table A-2. Estimates of juvenile survival rates necessary for population stability under different adult reproductive and survival rates.

Adult Survival	Reproductive Rate	Necessary Juvenile Survival
0.5	1.5	0.67
0.5	2.0	0.50
0.5	2.5	0.40
0.6	1.5	0.54
0.6	2.0	0.40
0.6	2.5	0.32

Major Populations: Genetic analyses of Burrowing Owls from three of the demographic study sites (Lemoore, Carrizo, Imperial Valley) failed to identify population differentiation (Korfanta 2001). This was likely due to the continuous habitat relative to the long-distance dispersal of juveniles and some adults (Rosier et al., unpubl. ms). Owls are most abundant within the Central and Imperial Valleys (Fig. A-1). Based on the survey of DeSante et al. (unpubl. ms), most (91%) Burrowing Owls occur on private lands. However, the difficulty of detecting Burrowing Owls nesting within large grasslands (Ronan 2002, Rosenberg et al., unpubl. data) coupled with the densities estimated for Carrizo (Table A-1) suggests that large publicly managed grasslands within public lands may have large numbers of Burrowing Owls.

State Status: Species of Special Concern—declining population levels, limited ranges, and/or continuing threats have made them vulnerable to extinction.

Natural Heritage Rank: G4/S2—imperiled in the state because of rarity or because of some factor(s) making it very vulnerable to extirpation from the state.

Habitat Use and Condition: Burrowing Owl nesting habitat is similar to the characteristics of land preferred for agricultural, residential, and commercial development. Because California's human population growth will continue, grassland and desert habitat can be expected to be further reduced. The primary regions of grasslands and deserts supporting Burrowing Owl populations are those managed by public agencies such as Bureau of Land Mangament and Department of Defense, although quantitative estimates of potential habitat have not yet been computed. Presumably, large areas of undeveloped deserts have sparse but stable (over the long-term) Burrowing Owl populations. Areas undergoing rapid urbanization, such as the San Francisco Bay area and many parts of southern California, have lost and will continue to lose habitats that once supported Burrowing Owl populations. The Central Valley and Imperial Valley have lost most of their native vegetation to large-scale agriculture, but Burrowing Owls are abundant (DeSante et al. *In press*; Rosenberg and Haley *In press*).

In California, Burrowing Owls have shown incredible tolerance for human encroachment and degradation of native habitats. In urban areas, they are often found nesting within landfills, golf courses, airports, and vacant lots within highly developed areas (Haug et al. 1993, Trulio 1997). The primary criterion for Burrowing Owl occurrence is a nest burrow. Because of this, habitat quality is spatially variable and highly dynamic. In modified ecosystems, habitat quality is often dependent on individual landholders and sensitive to a wide variety of land uses, such as farming practices.

Threats: Valley-bottoms in or near population centers are highly valued for residential and commercial development. Rapid development within the San Francisco Bay Area and other municipalities is responsible for declines in Burrowing Owl numbers in these areas. Further loss of Burrowing Owls on private lands within urban areas is expected under current land-use regulations. Because of the large numbers of Burrowing Owls that reside within the agricultural matrix of the Central and Imperial Valleys, change in methods of farming practices, particularly water conveyance, is likely to impact Burrowing Owl numbers (Rosenberg and Haley *In press*). Because Burrowing Owls in agricultural systems spend a large proportion of their time foraging in fields (Rosenberg and Haley *In press*), pesticide use will remain a threat to these populations. Some populations maintain substantial body burdens of persistent pesticides that may inhibit reproduction (Gervais et al. 2000), although these levels appear to fluctuate through time, making their impact difficult to predict (Gervais 2002). Throughout California, ground-squirrel control programs may affect Burrowing Owl numbers and persistence in local areas because most nest burrows are constructed by these species.

Burrowing Owls and their nests are protected by California Fish and Game Code and the U. S. Migratory Bird Treaty Act. Avoiding violation of these regulations usually requires that disturbance at occupied nest territories be reduced or eliminated during the nesting season. The California Environmental Quality Act offers some protection by stipulating that significant impacts to the species be mitigated. Although outright killing of the birds and active nests is addressed by California Fish and Game Code and the Migratory Bird Treaty Act, the loss of habitat is not. Existing regulatory mechanisms have not been effective at preventing or discouraging intentional destruction of Burrowing Owl habitat, including nest sites.

Vehicle collisions have been cited as a potentially significant source of mortality (Haug et al. 1993; Clayton and Schmutz 1997, Rosenberg et al., unpubl. data). The risk of vehicle collisions is likely greater in developed areas with dense human populations or along areas where Burrowing Owls nest predominately near roads.

Literature Cited:

California Burrowing Owl Consortium. 1997. Burrowing Owl survey protocol and mitigation guidelines. Appendix B, pp 171-177 *in* Lincer, J. L. and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

California Department of Fish and Game. 1995. Staff report on Burrowing Owl mitigation. Unpublished report.

Canfield, C. S. 1869. Habits of the Burrowing Owl in California. American Naturalist 2:583-586.

Clayton K. M., and J. K. Schmutz. 1997. Burrowing (*Speotyto cunicularia*) owl survival in prairie Canada. Pages 107-110 *in* J. R. Duncan, D. H. Johnson, and T. H. Nicholls, editors. Biology and conservation of owls of the northern hemisphere: 2nd International Symposium, Winnipeg, Manitoba, Canada. General Technical Report NC-190, USDA, Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Dawson, W. L. 1923. Birds of California, Volume 2. South Moulton Company, San Francisco, California.

DeSante, D.F., E.D. Ruhlen, S.L. Adamany, K.M. Burton and S. Amin. Pp.38-48 *in* Lincer, J.L. and K. Steenhof, Eds. 1997. The Burrowing Owl, It's Biology and Management: Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report No. 9.

DeSante, D. F., E. D. Ruhlen, and D. K. Rosenberg. *In press*. Density and abundance of burrowing owls in the agricultural matrix of the Imperial Valley, California. Studies in Avian Biology.

Gervais, J. A. 2002. Evaluating space use and pesticide exposure risk for Burrowing Owl in an agricultural environment. Ph.D. Dissertation, Oregon State Univ., Corvallis, Oregon.

Gervais, J. A., D. K. Rosenberg, D. M. Fry, L. Trulio and K. K. Sturm. 2000. Burrowing Owls and agricultural pesticides: evaluation of residues and risks for three populations in California, USA. Environmental Toxicology and Chemistry 19:337-343.

Grinnell, J. and A.H. Miller. 1944. The Distribution of the Birds of California. Cooper Ornithological Club. Berkeley, California.

Haley, K. A. 2002. The role of food limitation and predation on reproductive success of burrowing owls in southern California. M.S. Thesis, Oregon State Univ., Corvallis, Oregon.

Haug, E. A., B.A. Millsap and M.S. Martell. 1993. Burrowing Owl (*Speotyto cunicularia*). *in* A. Poole and F. Gill, editors. The Birds of North America, No. 61. The Academy of Natural Sciences, Philadelphia, PA and The American Ornithologists' Union, Washington, DC.

James, P. C. and T .J. Ethier. 1989. Trends in the winter distribution and abundance of Burrowing Owls in North America. American Birds 43:1224-1225.

Johnson, B. S. 1997. Demography and population dynamics of the Burrowing Owl. Pages 28-33 *in* J. L. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Korfanta, N. M. 2001. Population genetics of migratory and resident Burrowing Owls (*Athene cunicularia*) elucidated by microsatellite DNA markers. M.S. Thesis. University of Wyoming, Laramie, Wyoming.

Ronan, N. A. 2002. Habitat selection, reproductive success, and site fidelity of burrowing owls in a grassland ecosystem. M.S. Thesis, Oregon State University, Corvallis, Oregon.

Rosenberg, Daniel K., and K. L. Haley. *In press*. The ecology of Burrowing Owls in the agroecosystem of the Imperial Valley, California. Studies in Avian Biology.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966–2001. Version 2002.1. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

Sauer, J. R., S. Schwartz, and B. Hoover. 1996. The Christmas Bird Count Home Page. Version 95.1. Patuxent Wildlife Research Center, Laurel, Maryland.

Trulio, L. 1997. Burrowing Owl demography and habitat use at two urban sites in Santa Clara County, California. Pages 84-89 *in* J. L. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Sources of Unpublished Manuscripts and Data

DeSante, D. F., E. D. Ruhlen, and D. K. Rosenberg. The distribution and abundance of Burrowing Owls in California: evidence for a declining population. The Institute for Bird Populations, Contribution No. 58.

Gorman, L., D. K. Rosenberg, N. A. Ronan, K. L. Haley, J. A. Gervais, and V. Franke. In prep. Evaluation of methods for estimation of burrowing owl reproductive rates.

Rosenberg, D., L. Trulio, D. Chromczak, J. Gervais, K. Haley, and N. Ronan. Unpubl. data. Ecology of burrowing owls in California. (Data collected at four sites in California, 1996-2000.)

Rosier, J., N. Ronan, and D. Rosenberg. In revision. Breeding season survival and dispersal of Burrowing Owls in an extensive California Grassland. (Data collected at Carrizo Plain National Monument.)

Additional Contributors for California State Summary:

John H. Barclay[1]
Jennifer A. Gervais[2]
Katherine L. Haley[2]
Noelle A. Ronan[2]
Daniel K. Rosenberg[3]

[1] Albion Environmental, Inc., 1414 Soquel Ave., No. 205, Santa Cruz, CA 95062

[2] Department of Fisheries and Wildlife, 104 Nash Hall, Oregon State University, Corvallis, OR 97331.

[3] Department of Forest, Range, and Wildlife Sciences, 5230 Old Main Hill, Utah State University, Logan, UT 84322-5230.

Colorado

Summary: Burrowing Owls are a breeding species across the plains of e. Colorado, with scattered occurrences in the Grand Valley (wc. Colorado), the San Luis Valley (sc. Colorado), and South Park (c. Colorado; Jones 1998). During mild winters, rarely an individual will winter in Colorado. Based on survey results of state biologists, James and Espie (1997) estimated 1,000-10,000 pairs of Burrowing Owls in Colorado in 1992. Rocky Mountain Bird Observatory estimated the total Burrowing Owl population of e. Colorado to be 20,408 individuals based on driving line transects and 15,796 individuals based on road-based point counts (Hanni 2001). Some Colorado counties no longer have Burrowing Owls where they did occur within recent years (Andrews and Righter 1992, J. Slater, pers. commun.).

BBS: No significant trends were detected over any survey period (Sauer et al. 2002).

CBC: N/A

Atlas: According to the 1998 Colorado Breeding Bird Atlas, breeding was confirmed for the species in 18 latilong blocks and four of the ten west slope latilong blocks in which Burrowing Owls have occurred historically (Fig. A-3, Jones 1998). They were found in 40% of the priority blocks in the eastern plains and the number of blocks with Burrowing Owls gradually decreased from east to west and south to north. The distribution of blocks with Burrowing Owls approximated that found in 1999 surveys by the Rocky Mountain Bird Observatory (RMBO, formerly Colorado Bird Observatory) (Hutchings et al. 1999). Jones (1998) documented breeding in the Grand Valley from Grand Junction to the Utah border, but not in nw. Colorado or South and Middle Parks. Burrowing Owls were recorded in only three blocks in sw. Colorado and four in the San Luis Valley (Jones 1998). Level of breeding evidence for priority blocks with Burrowing Owls was 152 confirmed (59%), 54 probable (21%) and 53 possible (20%).

Research/Monitoring Biddle (1996) stated that burrows which are vacated by prairie dogs soon become unsuitable to Burrowing Owls as they fall into disrepair, but also suggested additional associations between prairie dogs and Burrowing Owls may decrease the suitability of sites for breeding in the absence of prairie dogs. From anecdotal evidence, she found that towns recently vacated by prairie dogs, yet with available burrows, did not contain breeding Burrowing Owls. She noted one town in Logan County, Colorado, had no prairie dogs or Burrowing Owls in 1994, and breeding Burrowing Owls were present in 1995 after prairie dogs recolonized the site. Ongoing research is continuing at the Rocky Mountain Arsenal National Wildlife Refuge investigating relationships between prairie dog populations affected by epizootic plagues and Burrowing Owl populations (M. Hetrick, pers. commun.).

Lutz and Plumpton (1999) banded 60% of the known population on the Rocky Mountain Arsenal as either adults or as nestlings from 1990-94. Most (n = 513; 92%) were never reencountered after the year they were banded. Of adults banded in 1990, 39% returned in 1991 while only 5% of chicks banded in 1990 returned (Plumpton and Lutz 1993). Overall, 42 banded Burrowing Owls (8%) returned to the area in one year and used the area for two-four years (Lutz and Plumpton 1999). Adult males and females returned at similar rates (19% and 14%, respectively). Adult males and females nested in formerly used sites at similar rates (75% and 63%, respectively). They found no difference in productivity between philopatric adults and presumed new adults; however, past brood size was greater for females that returned to former nest sites (mean = 4.9 ± 0.69 young) than for females that changed nest sites in subsequent years (mean = 2.2 ± 0.79 young; Lutz and Plumpton 1999). Females banded as nestlings returned as adults after a year absence from the study area. Males banded as nestlings returned in the year following hatch, with one exception. Fledging rate ranged from 0-9 young per nest (mean = 3.62 ± 0.19 young/nest, n = 167). The majority of returning adults (66%) reused the same prairie dog town as the prior year and 90% of prairie dog towns and 20% of nesting burrows were reused (Plumpton and Lutz 1993).

Plumpton (1992) found nesting Burrowing Owls occupied burrows with a shorter distance to the nearest road, and shorter grass and forb height than generally available, while using black-tailed prairie dog towns with greater burrow density and percentage of bare ground than available. VerCauteren et al. (*In review*) found Burrowing Owl density was inversely related to the area of prairie dog towns, but total number of Burrowing Owls was positively related to town size. In concordance with Plumpton (1992), VerCauteren et al. (*In review*) found the number of Burrowing Owls in e. Colorado was significantly correlated with number of prairie dogs and number of burrows. Biddle (1996) found the number of shortgrass patches within 1000 m of prairie dog towns could be used to predict the presence of Burrowing Owls in Logan County, Colorado, with the probability increasing as the number of patches increased. Plumpton (1992) found that periodic mowing could maintain vegetation structure for Burrowing Owls when prairie dogs were eliminated by epizootics or chemical extirpation.

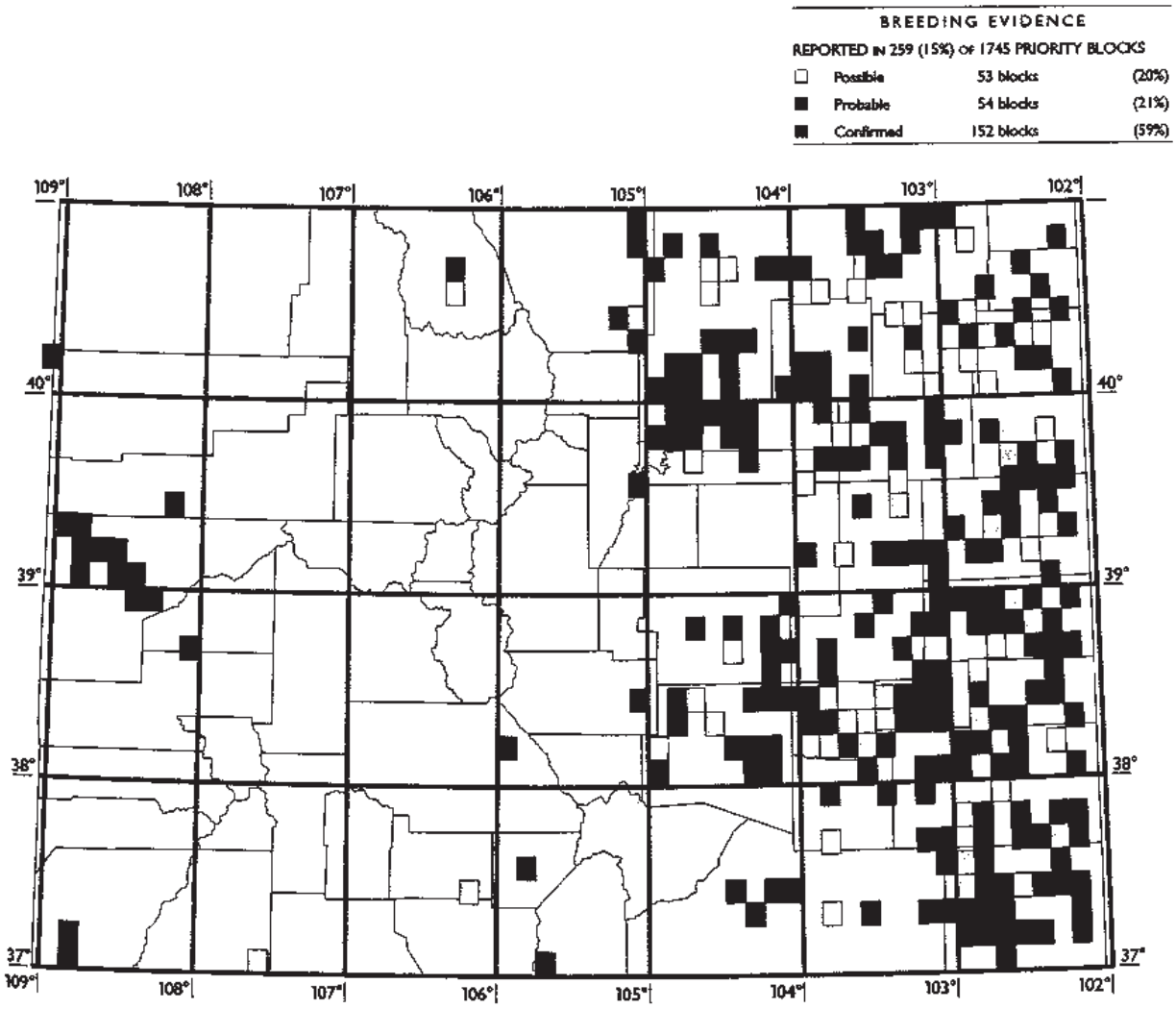

Fig. A-3. Distribution of Burrowing Owls in Colorado from the Colorado Breeding Bird Atlas project (Jones 1998).

Conservation Activities: Management efforts directed toward retention of active prairie dog towns (Plumpton 1992, Biddle 1996) and cropped vegetation (<8 cm) by either sciurids or mowing would be beneficial to nesting Burrowing Owls. The Colorado Division of Wildlife is planning to implement black-tailed prairie dog conservation efforts (J. Slater, pers. commun.).

The RMBO manages "Prairie Partners", a program that asks for voluntary cooperation from private landowners to conserve shortgrass prairie birds and their habitat through effective stewardship (Hutchings et al. 1999). In 1999, "Prairie Partners" documented 468 Burrowing Owl locations (79.3% on public land). Information is provided to landowners on shortgrass prairie conservation and Burrowing Owl natural history. The program also provided information about landowner attitudes toward Burrowing Owls and prairie dogs.

RMBO published "Sharing Your Land with Shortgrass Prairie Birds" (Gillihan et al. 2001) which includes a section on Burrowing Owl identification, natural history, and habitat requirements and a booklet focusing on grasslands and grassland birds for elementary and secondary classroom use (Hutchings et al. 1999). These materials are being distributed to landowners, managers, and schools.

Major Populations: Major populations are found at Rocky Mountain Arsenal in sc. Adams County and the following counties in Colorado according to VerCauteren et al. (2001): Baca, Bent, Cheyenne, Crowley, Kit Carson, Kiowa, Prowers, Pueblo, and Weld.

State Status: Threatened

Natural Heritage Rank: G4/S4B (S4—widespread, abundance, and apparently secure in state, with many occurrences during the breeding season, but of long-term concern).

Habitat Use and Condition: Habitat on the eastern plains is generally in good condition, but along the Front Range it is being rapidly converted to urban development. With the exception of Comanche and Pawnee National Grasslands (on the eastern plains), and a few other state and federal lands, Burrowing Owl habitat is found mostly on private lands (88% of eastern Colorado is in private ownership) (J. Slater, pers. commun.). Habitat loss is responsible for complete or near extirpation of Burrowing Owls in some areas; however, some areas have suitable habitat with no Burrowing Owls, thereby indicating other factors may be influencing Burrowing Owl populations in Colorado (Andrews and Righter 1992).

Threats: Rapid urban/suburban/exurban development along the Front Range of Colorado (Pueblo to Fort Collins) is reducing Burrowing Owl habitat by reduction of black-tailed prairie dogs and their habitat. Furthermore, direct eradication of prairie dogs is eliminating available burrows and short vegetation preferred by Burrowing Owls. Sylvatic plague events in prairie dogs are causing at least temporary reductions in habitat (J. Slater, pers. commun.). Increased use of desert areas in the Grand and Uncompahgre Valleys in w. Colorado has increase disturbance at many historical sites (R. Levad, pers. commun.).

The Burrowing Owl is a Colorado Threatened Species with an increased fine for killing them, but there are no legal implications for habitat destruction. The Colorado Division of Wildlife recommends Burrowing Owl surveys before any land development occurs and recommends avoidance measures, but there is no legal requirement to follow these recommendations (J. Slater, pers. commun.).

Research in Colorado indicated that radiotelemetry transmitter packages have a significant impact on Burrowing Owl behavior. Telemetered adults spent significantly less time resting and alert, and more time out-of-sight of nest burrows (Plumpton 1992). Telemetered Burrowing Owls also had significantly lower productivity than non-telemetered Burrowing Owls (D. Plumpton, unpubl. data).

Literature Cited:

Andrews, R., and R. Righter. 1992. Colorado Birds: A reference to their distribution and habitat. Denver Museum of Natural History, Denver, Colorado.

Biddle, P. B. 1996. Do landuse patterns influence Burrowing Owl nest site selection in northeastern Colorado? M.S. Thesis. Colorado State University, Fort Collins, Colorado.

Gillihan, S. W., D. J. Hanni, S. W. Hutchings, T. Toombs, and T. VerCauteren. 2001. Sharing your land with shortgrass prairie birds. Rocky Mountain Bird Observatory, Brighton, Colorado.

Hanni, D. J. 2001. Comparison of four methodologies used to monitor shortgrass prairie birds in eastern Colorado. Rocky Mountain Bird Observatory, Brighton, Colorado.

Hutchings, S., M. Carter, E. Atkinson, T. VerCauteren, C. Finley, S. Gillihan, and J. Nocedal. 1999. Prairie Partners: Promoting stewardship of shortgrass prairie. Unpubl. Rep., Colorado Bird Observatory, Brighton, Colorado.

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: an agency survey. Pages 3-5 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Jones, S. R. 1998. Burrowing Owl. Pages 220-221 *in* H. E. Kingery, editor. Colorado Breeding Bird Atlas. Colorado Breeding Birds Atlas Partnership and Colorado Division of Wildlife.

Lutz, R. S., and D. L. Plumpton. 1999. Philopatry and nest site reuse by Burrowing Owls: implications for productivity. Journal of Raptor Research 33:149-153.

Plumpton, D. L. 1992. Aspects of nest site selection and habitat use by Burrowing Owls at the Rocky Mountain Arsenal, Colorado. M.S. Thesis. Texas Technical University, Lubbock, Texas.

Plumpton, D. L., and R. S. Lutz. 1993. Nesting habitat use by Burrowing Owls in Colorado. Journal of Raptor Research 27:175-179.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966-2001. Version 2002.1 U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

VerCauteren, T. L., S. W. Gillihan, and S. W. Hutchings. 2001. Distribution of Burrowing Owls on public and private lands in Colorado. Journal of Raptor Research 35:357-361.

Although a separate subspecies from the Western Burrowing Owl (A. c. hypugaea), a state summary for the Florida Burrowing Owl (A. c. floridana) is included in this document to provide complete information on the species in the United States. This state summary is an update of information included in Millsap (1996).

Florida

Summary: Burrowing Owls are a mostly resident species primarily from c. Florida southward, though many northerly breeding birds apparently retreat to s. Florida during winter. Some breeding occurs regularly as far north as Duval County (as of 1975) and as far west as Okaloosa County (Eglin Air Force Base, as of 1993) in the western part of the Florida Panhandle. During 1995, a pair of Burrowing Owls summered but did not successfully breed in Decatur County, Georgia, near the Florida border, representing the furthest north breeding season occurrence, presumably of the Florida subspecies.

The Florida and Bahamas breeding populations have been named a separate subspecies (*A. c. floridana*) from populations in w. North America and populations elsewhere in the West Indies and South America (Ridgway 1914, Clark 1997). However, questions have been raised regarding the validity of morphological criteria used to determine subspecies within Burrowing Owls (Millsap 1996), as well as the identification of some Florida specimens collected during winter as representative of *A. c. hypugaea*, which have been found throughout the state (Stevenson and Anderson 1994). One female examined by Millsap from the breeding population in Okaloosa County exhibited characteristics of populations from western North America (Stevenson and Anderson 1994). Millsap (1996) recommends reevaluation of Burrowing Owl subspecies based on modern systematic methods, and some preliminary work in this regard is underway (Denton et al. *In review*).

The earliest treatments of Burrowing Owls in Florida indicated that most were located in the central Peninsular counties where dry prairies were most prevalent (Osceola, Okeechobee and DeSoto counties) and in the Gulf coastal lowlands, with the Tampa Bay area near the center (Rhodes 1892, Howell 1932, Bent 1938, Millsap 1996). Burrowing Owls have declined precipitously in these "natural" habitats with the loss of Florida prairies since the late 1800's (Bent 1938, Nicholson 1954, Owre 1978, Abrahamsom and Hartnett 1990, Cox et al. 1994, Stevenson and Anderson 1994, Millsap 1996). However, the species appears to have expanded since the 1940's through to at least the 1970's by taking advantage of human altered situations (airports, some agricultural situations with dirt canal banks and road berms, and early stages of development).

BBS: No significant trends detected for Florida (Sauer et al. 2002). However, for the few routes where Burrowing Owls were consistently detected (10 out of 81 statewide; 7 out of 34 in Peninsular Florida and 2 out of 10 in Subtropical Florida), the tendency was for fewer detections over time, but this may not be reflective of true population trends. High numbers of Burrowing Owls in Florida are concentrated in developing areas which are not generally well represented on BBS routes.

CBC: Insufficient data is available for determining clear trends from Christmas Bird Count (CBC) data. Over a three-year period (1993-1996, as a sample), Burrowing Owls were detected in two years on 11 Counts and in one year on eight Counts, out of a statewide total of 53 each year. The vast majority of CBCs each year detected fewer than 15 Burrowing Owls (8 of 11, 9 of 11, and 6 of 8, respectively). Many well-known breeding sites consistently fail to detect any Burrowing Owls during winter indicating either seasonal movements or an inherent decrease of detectability from breeding to non-breeding seasons. This species becomes mostly nocturnal during winter (Stevenson and Anderson 1994).

Atlas: The Florida Breeding Bird Atlas is unpublished, but data collected from 1987 – 1991 provide relative recent distributional data statewide. Atlas data show the Florida Burrowing Owl occurring over a relatively wide area of the state, from Madison and Duval counties south to the middle Keys. Within this broad range, the species can best be considered local and spotty in distribution and dependent on the availability of suitable habitat. During the BBA period, Burrowing Owls were conspicuously absent from the extensive wetlands of the Everglades and Big Cypress areas of South Florida, from the Panhandle, and from much of the northeastern Atlantic Coast (since then they have been observed nesting on Eglin AFB in the Panhandle).

Research/Monitoring There is no statewide monitoring program for Florida Burrowing Owls. Several local monitoring efforts have been undertaken in suburban and ruderal areas where Burrowing Owls have recently become established. Through these local monitoring efforts, we know that populations in many such areas collapse soon after densely packed housing or other development dominates the landscape (Courser 1976, Consiglio and Reynolds 1987, Millsap 1996).

A long-term research project has been underway in Cape Coral in sw. Florida to better document the reasons Burrowing Owl populations become established in some developing areas and then collapse at some threshold of development. This research has been undertaken with the goal of establishing management recommendations for communities interested in the conservation of this species (Millsap and Bear 1997, 2000, Millsap 2002). Burrowing Owls prefer "neighborhoods" when over

25% of the area is in developed lots but start to collapse when development exceeds 60%, possibly irretrievably so when over 70% of the area is in developed lots. Millsap (2002), presents data that adult males, adult females, and juveniles respond differently to landscape features in terms of survival and emigration. This complex situation requires more study, but it appears that some desirable level of development through zoning may allow for reasonably large and stable Burrowing Owl populations to persist within urban-suburban landscapes.

Conservation Activities: Active education programs appear to be working in Cape Coral to reduce harassment, and resulting nest failure, of Burrowing Owls. Most documented harassment is linked to school-aged children. The implementation of a formal "mandatory" Burrowing Owl education program in Cape Coral public schools has coincided with increasing local nesting success (Millsap and Bear 2000; similar results in Broward County have been reported, Consiglio and Reynolds 1987). Millsap and Bear (2000) also suggested buffer zones be established by the City of Cape Coral or developers, which can be useful in shielding owls from disturbance where construction is underway during the nesting season. They suggested a minimum of a 10-m buffer may be effective, but larger buffers are likely better. Finally, they suggested the most important conservation actions municipalities may undertake is to develop conservation agreements with the managers of public facilities such as schools, athletic fields, churches, parks, libraries, and office building complexes that provide open grounds necessary for Burrowing Owl habitat.

Although Burrowing Owl populations using urban-suburban environments have received much recent attention, it is still necessary to conserve populations persisting in natural habitats, especially Florida's dry prairies. Cox et al. (1994) used a combination of Breeding Bird Atlas (Kale et al. 1992) information and overlay of existing dry prairie acreage to address the site protection needs for this and other dry prairie associated species. They concluded that the greatest opportunities to conserve natural habitat for Burrowing Owl specifically on already identified conservation areas included the Kissimmee Prairie region, with Avon Park Air Force Range, Audubon Kissimmee Prairie Preserve, Arbuckle State Forest, and Three Lakes State Wildlife Management Area. This region supports key sites maintaining a large viable population of Burrowing Owls within historically important habitats. Outside existing conservation lands, there are patches of native dry prairie that could also be important for linking all the region's potentially isolated subpopulations together if these sites receive long-term protection from conversion. The priority sites include patches between Avon Park Air Force Range and Lake Kissimmee and between Avon Park Air Force Range and Three Lakes State Wildlife Management Area. With these connections in place, this entire region could constitute one large Florida Burrowing Owl population (Cox et al. 1994).

Two other concentration areas exist, worthy of conservation attention (Cox et al. 1994). The Miami Ridge presently supports sizeable population of Burrowing Owls in se. Florida, but these largely agricultural lands are quickly progressing towards urban-suburban development. Experiences in other similarly developing areas like Cape Coral may be useful for conserving these populations into the future. The last large concentration area considered here is along the western shore of Lake Okeechobee, which includes patches of remnant dry prairie and expansive agricultural lands, both which can provide suitable habitat for Burrowing Owls (Abrahamson and Hartlett 1990). Working in cooperation with private landowners is essential to conserve these isolated prairie remnants and the species dependent upon them, including Florida Burrowing Owls (see also Cox et al. 1994).

Major Populations: Bowen (2000) conducted a metapopulation analysis of Florida Burrowing Owls, which identified eight major subpopulations and 59 metapopulations in Florida (Table A-3). All major subpopulations were in south Florida, but the population on Eglin Air Force Base in the Panhandle is probably large enough to warrant inclusion here. Other central and north Florida metapopulations were present in 26 counties, but these were generally small in size, probably isolated, and had high predicted probabilities of extirpation.

State Status: Species of Special Concern (Millsap 1996; ranked by Millsap et al. 1990, with a Biological Score of 24). Burrowing Owls and their nests are protected by Commission rules (Chapter 39, Florida Administrative Code) and federal rules promulgated under the Migratory Bird Treaty Act (16 U.S.C. 703-712). The Florida Fish and Wildlife Conservation Commission requires that a permit be obtained from the agency before a Florida Burrowing Owl nest burrow can be destroyed.

Natural Heritage Rank: G4/S3 (Rare and uncommon in the state, Florida Natural Areas Inventory 2001)

Habitat Use and Condition: Habitat is best defined as very open well-drained treeless country, with short grassy or herbaceous vegetation maintained by regular and frequent grazing, mowing, or burning. Soil needs to be of a quality for Burrowing Owls to easily dig and maintain burrows. Although burrows of gopher tortoises or large fossorial mammals are used occasionally, in Florida most burrows used are dug by Burrowing Owls themselves.

These requirements were met historically in Florida on the dry prairies of the central peninsula in the vicinity of burns and along the edges of wetlands during dry periods (Howell 1932, Bent 1938, Millsap 1996). Land clearing and extensive drainage of

Table A-3. Distribution and abundance of Florida Burrowing Owls by major subpopulation and county.

Subpopulation	County	Est. population size (no. adults)	Source
Wellington Aerofield and golf course	Palm Beach	63	Bowen (2000)
Boynton Beach subdivisions	Palm Beach	64	Bowen (2000)
Pompano Beach Airport	Broward	69	Bowen (2000)
Ft. Lauderdale Executive Airport	Broward	77	Bowen (2000)
Cooper City, Penbrooke Pines, Davie	Broward	189	Bowen (2000)
Punta Gorda	Charlotte	37	Bowen (2000)
Cape Coral	Lee	756	Bowen (2000)
Marco Island	Collier	47	Bowen (2000)
Eglin Air Force Base	Santa Rosa and Okaloosa	25	Millsap (pers. obs.)

wetlands have led to expansion of habitat especially since the 1940's. Burrowing Owls still occur in remnant patches of dry prairie, but even here they are more often than not associated with canal banks and road berms even in otherwise "natural" habitat. The above habitat conditions are also featured in pastures converted to non-native grasses, airports, golf courses, athletic fields, and partially developed residential and industrial areas where expanses of mowed lawn and ruderal grassland are maintained (Millsap 1996).

Threats: Continued loss of native dry prairie habitat is a serious threat to many endemic taxa in Florida, but cumulative loss of this habitat is mitigated for Florida Burrowing Owls to a degree as they make use of a variety of altered situations. However, these altered habitats may be exposed to increased use of harmful chemicals, increased presence of predators (including domestic as well as feral and native), human harassment, and in some areas fire ants. In developed areas, most documented mortality is associated with vehicular collisions (Mealey 1997, Millsap 2002).

Although there is good evidence that a moderate degree of development in some areas can support large Florida Burrowing Owl populations, too much development leads eventually to population collapse. Habitat set aside programs will be needed to ensure long-term persistence for most of these populations (Millsap 1996).

Millsap (1996) concluded that Florida Burrowing Owls did not appear to warrant further legal protection at that time, but recommended continued or expanded monitoring of local populations, especially in urban-suburban environments. The Florida Fish and Wildlife Conservation Commission will be collecting data to determine if current management actions are maintaining population numbers in Cape Coral, perhaps the most significant subpopulation.

Recommendation on Current Status for the Florida Burrowing Owl: Population trend data are lacking or insufficient for Burrowing Owls in Florida. Limited data indicate that it is decreasing in some areas, but also has stable or increasing populations in others. The Florida Burrowing Owl continues to occupy the majority of its historical range and may have expanded into new areas. However, historical and continuing loss and reduction of dry prairies and an unclear future of urban/suburban population centers are the primary threats to this subspecies in Florida.

Currently, the Burrowing Owl is listed by the USFWS as a Bird of Conservation Concern-2002 (U.S. Fish & Wildlife Service 2002) in the Peninsular Florida and Southeastern Coastal Plain Bird Conservation Regions and in the USFWS Region 4 (Southeast Region). This designation is intended to stimulate collaborative, proactive conservation actions among public and private land managers and other partners. Recommended conservation measures include efforts to more accurately monitor population demographics and trends, and to better understand factors affecting populations now concentrated in urban/suburban areas of Peninsular Florida.

The Migratory Bird Management program of the USFWS recommends retaining the Florida Burrowing Owl on the BCC lists on which it currently appears. The listing of the Florida Burrowing Owl as a Bird of Conservation Concern highlights its potential vulnerability and need for increased monitoring and conservation attention by multiple Federal and State agencies and private organizations. The success of these efforts will be reviewed every five years as the Birds of Conservation Concern list is revised (U.S. Fish & Wildlife Service 2002).

Literature Cited:

Abrahamson, W. G. and D. C. Hartnett. 1990. Pine flatwoods and dry prairies. Pages 103-149 *in* R. L. Myers and J. J. Ewel, editors. Ecosystems of Florida. University of Central Florida Press, Orlando, Florida.

Bent, A. C. 1938. Life histories of North American birds of prey. Part 2. U.S. National Museum Bulletin No. 170.

Bowen, P. 2000. Demographic, distribution, and metapopulation analyses of the burrowing owl (*Athene cunicularia*) in Florida. M.S. Thesis, University of Central Florida, Orlando, FL.

Clark, R. J. 1997. A review of the taxonomy and distribution of the Burrowing Owl (*Speotyto cunicularia*). Journal of Raptor Research Report 9:14-23.

Consiglio, B., and G. Reynolds. 1987. Broward's Burrowing Owl watchers. Florida Naturalist 60:3-5.

Couser, W. D. 1976. A population study of the Burrowing Owl near Tampa, Florida. M.S. Thesis, University of South Florida, Tampa, Florida.

Cox, J., R. Kautz, M. Mac Laughlin, and T. Gilbert. 1994. Closing the gaps in Florida's wildlife habitat conservation system. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Denton, W., Q. Q. Fang, R. Chandler, and B. A. Millsap. *In review.* Genetic variations among populations of Florida borrowing owls using single strand-conformation polymorphism. Georgia Southern University, Statesboro, Georgia.

Florida Game and Fresh Water Fish Commission. 1990. Official lists of endangered and potentially endangered fauna and flora in Florida. 1 August 1990. Tallahassee, Florida.

Florida Natural Areas Inventory. 2001.Tracked species—vertebrates. FNAI, Tallahassee, Florida.

Howell, A. H. 1932. Florida bird life. Coward-McCann, New York, New York.

Kale, H. W., II, B. Pranty. B. Stith, and W. Biggs. 1992. An atlas of Florida's breeding birds. Final Report. Nongame Wildlife Program, Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Mealey, B. 1997. Reproductive ecology of the Burrowing Owls, *Speotyto cunicularia floridana*, in Dade and Broward Counties, Florida. Journal of Raptor Research Report 9:74-79.

Millsap, B. A. 1996. Florida Burrowing Owl. Pages 579-587 *in* J. A. Rodgers, Jr., H. W. Kale II, and H. T. Smith, editors. Rare and Endangered Biota of Florida, Vol V. Birds. University Press of Florida, Gainesville, Florida.

Millsap, B. A. 2002. Survival of Florida Burrowing Owls along an urban development gradient. Journal of Raptor Research 36:3-10.

Millsap, B. A., and C. Bear. 1997. Territory fidelity, mate fidelity, and dispersal in an urban-nesting population of Florida Burrowing Owls. Journal of Raptor Research Report 9:91-98.

Millsap, B. A., and C. Bear. 2000. Density and reproduction of Burrowing Owls along an urban development gradient. Journal of Wildlife Management 64:33-41.

Millsap, B. A., J. A. Gore, D. E. Runde, and S. I. Cerulean. 1990. Setting priorities for the conservation of fish and wildlife species in Florida. Wildlife Monographs No. 111.

Nicholson, D. J. 1954. The Florida Burrowing Owl; a vanishing species. Florida Naturalist 27:3-4.

Owre, O. T. 1978. Florida Burrowing Owl. Pages 97-99 *in* H. W. Kale II, ed. Rare and endangered biota of Florida. Volume 2 birds. University Presses of Florida, Gainesville, Florida.

Rhodes, S. N. 1892. The breeding habits of the Florida Burrowing Owl (*Speotyto cunicularia floridana*). Auk:9:1-8.

Ridgway, R. 1914. The birds of North and Middle America. Part IV. U.S. National Museum Bulletin No. 50.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966-2001. Version 2002.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

Stevenson, H. M., and B. H. Anderson. 1994. The birdlife of Florida. University Press of Florida, Gainesville, Florida.

U.S. Fish & Wildlife Service. 2002. Birds of Conservation Concern 2002. U.S. Department of Interior, Fish and Wildlife Service, Administrative Report, Arlington, Virginia.

Wesemann, T. 1986. Factors influencing the distribution and abundance of Burrowing Owls (*Athene cunicularia*) in Cape Coral, Florida. M.S. Thesis. Appalachian State University, Boone, North Carolina.

Wesemann, T., and M. Rowe. 1987. Factors influencing the distribution and abundance of Burrowing Owls in Cape Coral, Florida. Pages 129-137 *in* L. W. Adams and D. L. Leedy, editors. Integrating man and nature in the metropolitan environment. Proceedings of the national symposium on urban wildlife. National Institute for Urban Wildlife, Columbia, Maryland.

Additional Authors for Florida State Summary:

Brian A. Millsap, Florida Fish and Wildlife Conservation Commission, 620 S. Meridian St., Tallahassee, FL 32399-1600.

(Current address: Division of Migratory Bird Management, U.S. Fish and Wildlife Service, 4401 N. Fairfax Drive MS 634, Arlington, VA 22203)

William C. Hunter, U.S. Fish and Wildlife Service, 1875 Century Blvd., Suite 240, Atlanta, GA 30345.

Idaho

Summary: Burrowing Owls are a locally common summer resident in s. Idaho. The only evidence that the species ever occurred in n. Idaho is a statement by Merriam in 1891 that it was reported by Bendire as nesting at Fort Lapwai (Nez Perce County) (Burleigh 1972). Birds arrive in s. Idaho in early March and young have been observed near natal burrows as early as 10 June and as late as 17 September (Rich 1986). Populations are believed to be generally increasing (K. Steenhof, pers. commun.) Current distribution and relative abundance information has been well documented for several small scale study areas on the Snake River Plain and vicinity. James and Espie (1997) estimated 1,000 to 10,000 pairs in Idaho based on a survey of state wildlife agencies in 1992. Habitat loss and possible impacts to local populations from agricultural activities have been noted (Rich 1986, James and Espie 1997). However, the extent to which agriculture and other habitat disturbances have impacted Burrowing Owl populations is unknown as the species nests in close proximity to cultivated fields in the Snake River Plain, roadsides (Belthoff and King 1997), firing ranges (Lehman et al. 1999), and other disturbed areas in and around sagebrush-steppe habitat (Rich 1986).

BBS: Significantly increasing trends were detected for all survey periods: 1966-2001 (Trend = 19.1, P <0.07, n = 9); 1966-1979 (Trend = 39.2, P <0.03, n = 3), and 1980-2001 (Trend = 28.4, P <0.06, n = 9). Data credibility is low due to small sample sizes and high variance (Sauer et al. 2002).

CBC: N/A

Atlas: Historical and current records of Burrowing Owls in Idaho documented confirmed breeding in 12 out of 29 latilong blocks, predominantly in s. Idaho (Stevens and Struts 1991). Circumstantial evidence of breeding Burrowing Owls is recorded for two additional latilong blocks including the single historical account of a nesting pair in n. Idaho on Fort Lapwai, Nez Perce County as reported in Burleigh (1972).

Research/Monitoring Rich (1986) investigated vegetative and topographical characteristics around 80 occupied Burrowing Owl nest sites in the sagebrush-steppe of sc. Idaho. Burrowing Owls used burrows provided by badgers in open soil. In small lava outcrops, Burrowing Owls exhibited a preference for burrows excavated by yellow-bellied marmots. Cover within a 50-m radius of 80 occupied burrows was mainly bare earth, cheatgrass, rock, and annual forbs. In comparison to randomly chosen sites, occupied sites had a greater cover of cheatgrass, greater habitat diversity, were lower in elevation, and were more frequently located on southerly aspects. Occupied sites had less acreage of farmland and big sagebrush compared to unoccupied sites. Burrow security and prey availability, especially the proximity to populations of montane voles on farmland, may explain some of the habitat selection observed (Rich 1986).

Gleason and Johnson (1985) found that 75% of the nesting pairs used burrows excavated by badgers and the remainder occupied natural cavities in lava flows. Density was 1 pair/58 km^2. Average productivity was 3.6 young/nesting pair. Weather and diet influenced productivity with average productivity in a normal precipitation year (1976) and low productivity during drought (1977). Of 22 mortalities (two nestlings, 15 juveniles, and five adults), six (27%) were from vehicle collisions. Badger predation was presumed to be significant prior to emergence of young from nest burrows, but most mortality occurred after fledging when young were most likely vulnerable to starvation. Gleason and Johnson (1985) also found large portions of the study area lacked Burrowing Owls apparently due to factors other than the availability of nest sites.

Lehman et al. (1998, 1999) studied 235 Burrowing Owl nesting attempts between 1991-1994 on the Snake River Birds of Prey National Conservation Area (SRBPNCA), in sw. Idaho. Nest success was studied in relationship to disturbance caused by military training activities in the Orchard Training Area (OTA) in the SRBPNCA. There were no significant differences in nest success between nests located within versus outside of the OTA. Since most military activity occurred after Burrowing Owls established nesting areas and laid eggs, Lehman et al. (1999) suggested that military activity did not play an important direct role in the distribution of raptor nests in the OTA. Furthermore, direct impact to nests was restricted to a relatively small proportion of nesting pairs each year. If confirmation of nesting is made when young emerge from burrows, Mayfield estimates of nest success are likely to be inflated as they were in this study (100%, as all nests found at this stage were successful). Other methods of estimating nest success yielded lower estimates (64-71%, Lehman et al. 1998). Rate of nest reoccupancy in this study was 11% from 1991 to 1992, and 42% from 1993 to 1994.

In sw. and sc. Idaho, Belthoff and King (1997) reported nest success was 94.4% with 4.6 ± 1.8 young/nest in the Kuna Butte area (Ada County) and 92.9% with 5.1 ± 2.4 young/nest the Grand View area (Elmore County). Radio-tagged Burrowing Owls dispersed an average of 1.4 km from natal burrows during the post-fledging period (Belthoff et al. 1995).

Turnover of individuals in the Kuna Butte area appeared to be relatively high based on low rates of return by both adults and young. Of 52 nestling Burrowing Owls banded in the Kuna Butte study area in 1995, two (one male, one female) were detected in the area in 1996. These owls bred 1.8 and 4.8 km from their natal burrows. Of five adult males banded as breeders during 1995, two returned in 1996 and used the same burrows but acquired

different mates. Of 14 adult females banded in 1995, two returned to breed in 1996 and used burrows 106 m and 503 m from their 1995 burrows. Mate retention was uncertain with these females. Belthoff and King (1997) felt the difference in return rates between adults was a result of greater female dispersal rather than increased mortality.

Individual burrows were frequently reoccupied in multiple years (Belthoff and King 1997). Of 30 known nest burrows in 1994-95, 50% were reused in a subsequent year. Five burrows were used for nesting in all three years of study and nine others were used for at least two years. Of 10 burrows that fledged young in 1994, 70% were reused at least once. Conversely, burrows tended to remain unoccupied in years following nest failures; six nests remained unused in 1995-96 after failing in 1994 (Belthoff and King 1997).

In another study of nest reoccupancy, Rich (1984) found that 69.4% of previously documented nest burrows were reoccupied. Burrows in rock outcrops were reused 57.5% of the time compared to 31.4% for nests in soil mounds. Outcrop sites also were used more often in consecutive years; 23 were used for two years, and 12 were used for three consecutive years. Fifteen mound nests were used for two years, five were used for three years, and one was used four consecutive years. Greater reuse of outcrop sites was likely related to security; no burrows in outcrops were destroyed while 26 old badger burrows containing nests were filled in by plowing, cattle trampling, drifting sand, dredging, and other unknown causes (Rich 1984). It was unclear why some burrows were not used more regularly, as the changing of burrows could not be attributed to burrow characteristics or to changes in the surrounding habitat. Regardless of an abundance of burrows in suitable habitat, some Burrowing Owls apparently relocate from year to year.

Major Populations: Rich (1986) documented 242 occupied Burrowing Owl nests between 1976-83 in sc. Idaho. Lehman et al. (1999) documented 235 Burrowing Owl nest attempts between 1991-94 on and near the OTA, also on the SRBPNCA. In sw. Idaho (Ada and Elmore counties), Belthoff and King (1997) located 30 Burrowing Owl burrows in 1994-1995. In se. Idaho, Gleason and Johnson (1985) found average densities of 1 pair/58 km^2.

State Status: Protected Nongame Species. No person shall take or possess protected nongame species including nests and eggs at any time or in any manner, subject to fine and possible imprisonment (Idaho Statutes 36-1102 & 36-1402). Habitat protection is not included in State protection law.

Natural Heritage Rank: G4/S3S4 (S3—rare and uncommon in the state, S4—widespread, abundant, and apparently secure in state, with many occurrences, but of long-term concern).

Habitat Use and Condition: On the SRBNCA, 77% of Burrowing Owl nest sites had farmland within a 693 m radius (Rich 1986). Hay was a common crop and variation in cutting dates made rodents readily available throughout the Burrowing Owl breeding season.

Sagebrush is an important habitat type on occupied sites along the Snake River; however, continuous stands of dense sagebrush (10-35% canopy cover) were not occupied by Burrowing Owls (Rich 1986). Also in s. Idaho, 30 of 36 occupied Burrowing Owl nests were located within l00 m of sagebrush (Rich 1986).

Belthoff and King (1997) found that fires did not adversely affect Burrowing Owls in their study area. All nest sites which burned in 1995 were reoccupied in 1996. Several additional burrows within burned areas (but with unknown histories) were occupied by Burrowing Owls in 1996. The fires did not cause direct mortality of adult or juvenile Burrowing Owls (already of fledging age). These owls were repeatedly observed at burned sites for several weeks after fires. Also, juvenile owls from other families dispersed into burned areas immediately following fires in 1995 (Belthoff and King 1997).

Burrowing Owls in sw. Idaho nested in sites close to roads and agricultural fields, and in areas containing exotic plant species such as cheatgrass, tumble mustard, and annual wheatgrass (Belthoff and King 1997). Rich (1986) found that cover within 50 m of the burrows indicated that sites had been disturbed by fire and grazing. However, the dominant plants were not indicative of the highest degree of disturbance possible in sagebrush-steppe habitats (Rich 1986).

Threats: Invasion of shrubby species may contribute to population declines (Rich 1986). Belthoff and King (1997) noted nest burrows destroyed by agriculture and fire rehabilitation. Natural habitat has decreased due to increasing use of irrigation and the growing importance of agriculture in the state (Burleigh 1972). Soil mound nests were destroyed by plowing, cattle trampling, drifting sand, dredging, and other unknown causes (Rich 1984).

Literature Cited:

Belthoff, J. R., R. A. King, J. Doremus, and T. Smith. 1995. Monitoring post-fledging Burrowing Owls in southwestern Idaho. U.S. Bureau of Land Management, Idaho State Office, Technical Bulletin No. 95-8.

Belthoff, J. R., and R. A. King. 1997. Between-year movements and nest burrow use by Burrowing Owls in southwestern Idaho. Technical Bulletin No. 97-3, Idaho Bureau of Land Management.

Burleigh, T. D. 1972. Burrowing Owl. pp. 168-169 *in* Birds of Idaho. Caxton Printers, Ltd., Caldwell, Idaho.

Gleason, R. S., and D. R. Johnson. 1985. Factors influencing nesting success of Burrowing Owls in southeastern Idaho. Great Basin Naturalist 45:81-84.

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: an agency survey. Pages 3-5 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Lehman, R. N., L. B. Carpenter, K. Steenhof, and M. N. Kochert. 1998. Assessing relative abundance and reproductive success of shrubsteppe raptors. Journal of Field Ornithology 69:244-256.

Lehman, R. N., K. Steenhof, M. N. Kochert, and L. B. Carpenter. 1999. Effects of military training activities on shrub-steppe raptors in southwestern Idaho, USA. Environmental Management 23:409-417.

Rich, T. 1984. Monitoring Burrowing Owl populations: implications of burrow re-use. Wildlife Society Bulletin 12:178-180.

Rich, T. 1986. Habitat and nest-site selection by Burrowing Owls in the sagebrush steppe of Idaho. Journal of Wildlife Management 50:548-555.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966–2001. Version 2002.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

Stevens, D.A. and S. H. Struts 1991. Idaho Bird Distribution. Idaho Museum of Natural History. Special Publication No. 11.

Iowa

Summary: Northwest Iowa is on the eastern edge of the Burrowing Owl range. There is little to suggest that this species was ever common; the pattern of occurrence suggests periods of range expansion and regression. Some birds nested in the 1960s and 1980s (Dinsmore et al. 1984). Tallgrass prairie in the pre-settlement era was likely too dense for Burrowing Owls. To date, most records have been in pasturelands (J. Dinsmore, pers. commun.).

BBS: N/A

CBC: N/A

Atlas: Only a single record for the Burrowing Owl was reported (J. Dinsmore, pers. commun.).

Research/Monitoring Monitoring is restricted to reports from birdwatchers and incidental observations by biologists. No database for records is known. Not actively monitored by Iowa Department of Fish and Wildlife personnel (D. Howell, pers. commun.).

Conservation Activities: None reported.

Major Populations: None.

State Status: Placed in original Threatened list in 1977 due to low abundance; removed and designated Accidental Breeder in 1994 (D. Howell, pers. commun.).

Natural Heritage Rank: G4/SAB (Accidental breeder)

Habitat Use and Condition: Burrowing Owls are found in grasslands and pastures (Dinsmore et al. 1984). Pasturelands are preferred over ungrazed tallgrass prairie due to excessive cover on the latter. Most native prairie is under intense rowcrop agriculture, and is unsuitable, but no records exist to indicate the species was ever common.

Threats: Remnant tallgrass prairies provide unsuitable habitat due to excessive cover. Potential Burrowing Owl habitat has been lost to rowcrop agriculture (J. Dinsmore, pers. commun.).

Literature Cited:

Dinsmore, J. J., and T. H. Kent, D. Koenig, P. C. Peterson, and D. M. Roosa. 1984. Iowa Birds. Iowa State University Press, Ames, Iowa.

Kansas

Summary: Little data regarding Burrowing Owls in Kansas is available. Reports indicate it was "abundant" and "common" in the late 1800s in c. and w. Kansas. Burrowing Owls are currently considered uncommon summer residents in w. Kansas, but may be common in local areas. Prairie dogs have been nearly extirpated from many counties in c. Kansas, and sightings of Burrowing Owls are very localized. State agencies in 1992 reported the Burrowing Owl populations as between 100 and 1000 pairs, but decreasing due to reduced burrow availability (James and Espie 1997); however, this population estimate is disputed and believed to be in the 1,000 to 10,000 pair category (W. Busby, pers. commun.).

BBS: No significant trends were detected over any survey period (Sauer et al. 2002).

CBC: N/A

Atlas: Burrowing Owls were confirmed in 46 blocks, with probable and possible breeding occurring in 29 and 25 blocks, respectively (Fig. A-4). Burrowing Owls were observed only in the western half of the state where occurrences generally coincided with remaining areas of shortgrass prairie (Busby and Zimmerman 2001).

Research/Monitoring Burrowing Owl research and monitoring in Kansas is limited to natural history accounts and the Breeding Bird Survey which is too imprecise to detect population trends in this state.

Conservation Activities: None documented.

Major Populations: Burrowing Owl populations are highest in the shortgrass prairie region of Kansas. One of the state's largest populations is at Cimarron National Grassland in southwestern Kansas (W. Busby, pers. commun.).

State Status: No special status designated.

Natural Heritage Rank: G4/S3B, SZN (rare and uncommon breeding populations in the state, no non-breeding occurrences).

Habitat Use and Condition: Not reported.

Threats: Prairie dog populations and associated Burrowing Owl habitat appear stable although at levels far below historic levels. In the long term, increases in prairie dog populations are needed to create more Burrowing Owl habitat (W. Busby, pers. commun.).

Literature Cited:

Busby, W. H., and J. L. Zimmerman. 2001 The Kansas Breeding Bird Atlas. University Press of Kansas, Lawrence, Kansas.

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: an agency survey. Pages 3-5 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966-2001. Version 2002.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

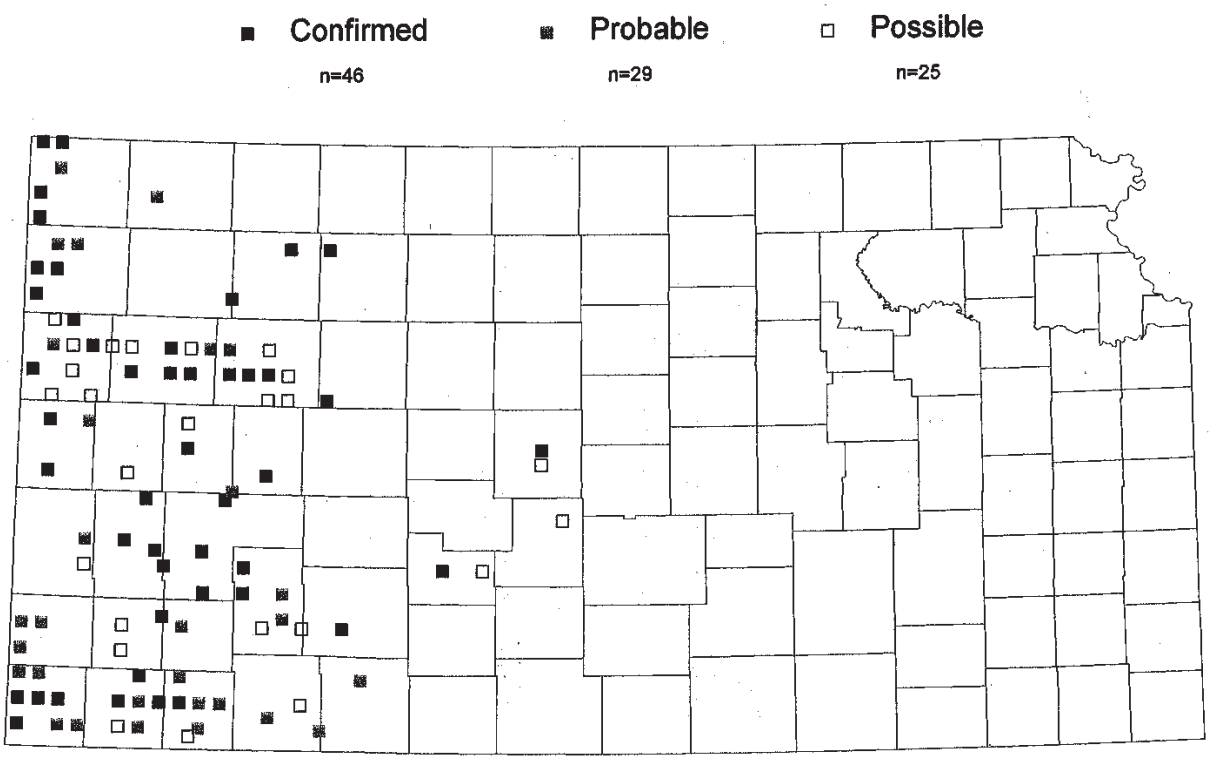

Fig. A-4. Distribution of Burrowing Owls in Kansas from the Kansas Breeding Bird Atlas project (Busby and Zimmerman 2001).

Minnesota

Summary: The Burrowing Owl was a regular to common breeding bird in the prairies of w. Minnesota in the first half of the century, but began to decline between approximately 1940 and 1960. The Burrowing Owl is now considered a very rare or casual resident in the sw. and wc. regions. Only ten documented breeding records exist from 1965-1985 (Janssen 1987, Martell et al. 2001). Reintroduction attempts from 1986-90 were unsuccessful; no returning Burrowing Owls were found in the years subsequent to release. Also, no successful natural nests were documented in 1992-98, despite significant efforts to locate the species (Martell et al. 2001).

BBS: N/A

CBC: N/A

Atlas: Unknown

Research/Monitoring Martell et al. (2001) located 13 natural nests at eight sites in Rock, Pipestone, Travers, and Yellow Medicine Counties, Minnesota during 1986-1990. Mean reproductive success was 3.54 young/pair. Nesting habitats included alfalfa fields (37.5%), pasture, (37.5%), roadside ditch (12.5%), and fenceline (12.5%).

During 1986-1990, 105 pre-flight juvenile Burrowing Owls were released (9 in 1986, 18 in 1987, 21 in 1988, 27 in 1989, and 30 in 1990). Eight fledgling mortalities were documented in the release area. No individuals were relocated after leaving the hack site and no successful nesting attempts were documented 1991-1998 (Martell et al. 2001).

Conservation Activities: Reintroduction of Burrowing Owls was attempted within the historic range in w. Minnesota from 1986-90 (Martell et al. 2001) but discontinued since no owls returned to breed in subsequent years. Land management reported in Martell et al. (2001) focused on protection and enhancement of nesting sites. Landowners were encouraged to maintain fields used by nesting Burrowing Owls in current rotations (e.g., alfalfa) or to enroll those fields in federal agricultural set-aside programs. In 1989, 24 artificial nest burrows were installed near natural burrows to provide alternate nest sites for returning pairs of owls or their offspring. One pair of owls nested and fledged seven young from an artificial burrow the year after their natural burrow collapsed. The artificial structure was located in the same field, approximately 40 m from the original burrow (Henderson 1984, Martell et al. 2001).

No management or research is currently planned beyond protection under current state and federal legislation (e.g., Migratory Bird Treaty Act, Minnesota Endangered Species Act). Should this situation change, habitat protection, management, and public education and cooperation will remain important. Selective use of reintroductions may also be useful in enhancing these efforts (Martell et al. 2001).

Major Populations: None. The Burrowing Owl is considered a very rare or casual resident in the sw. and wc. regions of Minnesota.

State Status: Endangered

Natural Heritage Rank: G4/S1 (Critically imperiled because of extreme rarity or other factor making it especially vulnerable to extirpation)

Habitat Use and Condition: In Minnesota, Burrowing Owls typically select heavily grazed pasture or mixed-grass prairie with colonies of Richardson's ground squirrels (Coffin and Pfannmuller 1988). Martell et al. (2001) reported nesting Burrowing Owls in alfalfa fields, suggesting some potential adaptability to agricultural habitats. Loss of pastures and prairies in western Minnesota has been a factor in the decline of Burrowing Owls in the state. However, some seemingly suitable habitat remains unused.

Threats: Loss of prairie and pasture habitats represent the primary threat to Burrowing Owls in Minnesota (Grant 1965, Martell et al. 2001).

Literature Cited:

Coffin, B., and L. Pfannmuller. 1988. Burrowing Owl. Page 264 *in* Minnesota's Endangered Flora and Fauna. B. Coffin and L. Pfannmuller, editors. University of Minnesota Press, Minneapolis, Minnesota.

Grant, R. A. 1965. The Burrowing Owl in Minnesota. Loon 37:2-17.

Henderson, C. L. 1984. Woodworking for wildlife: homes for birds and mammals. Minnesota Department of Natural Resources, St. Paul, Minnesota.

Janssen, R. B. 1987. Birds in Minnesota. University of Minnesota Press, Minneapolis, MN.

Martell, M. S., J. Schladweiler, and F. Cuthbert. 2001. Status and attempted reintroduction of Burrowing Owls in Minnesota, USA. Journal of Raptor Research 35:331-336.

Montana

Summary: The Burrowing Owl is a rare breeder in Montana. The majority of confirmed Burrowing Owl breeding records are east of the continental divide in association with black-tailed prairie dog and Richardson's ground squirrel colonies. Breeding west of the continental divide is probably associated with badger-enlarged Columbian ground squirrel burrows.

Marti and Marks (1989) reported the Burrowing Owl as common in Montana with a stable population trend from 1977-86. However, no records for number of nesting pairs or number of nest sites were reported. Based on a survey of state wildlife agencies, James and Espie (1997) estimated 100 to 1,000 pairs of Burrowing Owls in Montana in 1992 with a stable population trend. Atkinson (2000) estimated 644 ± 114 Burrowing Owl pairs in known prairie dog colonies in Montana.

BBS: No significant trends were detected over any survey period (Sauer et al. 2002).

CBC: N/A

Atlas: No atlas available. The Montana Bird Distribution shows evidence of breeding in 25 latilongs and indirect evidence in an additional 13 latilongs between 1991-95 (Fig. A-5). Nonbreeding observations encompass another 7 latilongs and there were no records of Burrowing Owls in 2 latilongs (Montana Bird Distribution Committee 1996).

Research/Monitoring Atkinson (2000) derived an estimate of Burrowing Owl population size through analyses of the one-stage stratified random sample obtained from surveys in 1999. Surveyors detected 474 owls with at least 123 pairs; occupancy rate was 38.2% (78 of 204 colonies). Atkinson (2000) estimated the Burrowing Owl population size at 644 ± 114 pairs in known prairie dog colonies in Montana. As supporting evidence, Atkinson (2000) estimated 819 pairs by direct extrapolation of the pair density (123 pairs / 10,079 acres) from surveyed colonies to the known colony acreage statewide (67,080 acres). In identical fashion, he estimated 787 pairs by extrapolating 123 pairs / 209 colonies to 1,337 known colonies. Atkinson (2000) stated that c. Montana, the Charles M. Russell National Wildlife Refuge (NWR), the Custer area in Custer and Prairie counties, s. Chouteau County, and Phillips County were adequately sampled. Parts of Wheatland County, the Northern Cheyenne and Fort Belknap reservations, and Rosebud and s. Custer counties were not adequately sampled in 1999.

A population estimate of 864 Burrowing Owl pairs was derived for four study areas in eastern Montana (Fort Belknap Reservation, South Phillips County, Custer Creek, and Northern Cheyenne Reservation. Restani et al. (2001) documented one Burrowing Owl pair/110 ha of prairie dog town habitat in southeastern Montana in 1998. Prairie dog towns occupied by Burrowing Owls were similar in size to unoccupied towns and no selection was demonstrated for or against towns subjected to recreational shooting or grazing. Occupied nests were closer to active prairie dog burrows than random locations; otherwise Burrowing Owl nest sites were not different than random sites in numerous habitat characteristics (Atkinson 2000, Restani et al. 2001).

Mean Burrowing Owl productivity was 2.6 ± 0.4 young/pair (n = 13) and was not correlated with number of active or inactive burrows, total number of burrows, or town size (Restani et al. 2001). Productivity was not influenced by recreational prairie dog shooting (2.3 young/pair on shot towns; 2.9 young/pair elsewhere).

Prairie dog towns were similar in size and mean burrow density in 1991 and 1998; however, total acreage of prairie dog habitat increased slightly (Restani et al. 2001). Burrowing Owls were present at 16% of prairie dog towns surveyed in 1998 compared to 4% in 1996 (Wittenhagen and Tribby 1996), 14%, in 1991 (Richardson and Tribby 1991), and 27 % in 1978-79 (Restani et al. 2001, Knowles *In review*). Restani et al. (2001) felt the low density of breeding owls, high nearest neighbor distances, and abundant unoccupied habitat suggested the Burrowing Owl population was well below carrying capacity on their study site in southeastern Montana.

Conservation Activities: Indicator colonies will be selected and surveyed on a yearly basis for long-term trends and distribution in addition to randomly selected sites (Atkinson 2000).

Major Populations: Montana's largest prairie dog complex occurs in Phillips and Blaine counties and appears to contain Montana's largest Burrowing Owl complex (currently ~11,336 ha (28,000 ac). Prairie dog colony acreage in this complex appeared to peak in the early 1990s (~21,457 ha (53,000 ac)) (Knowles *In review*).

State Status: Species of Special Concern

Natural Heritage Rank: G4/S3B, SZN (rare and uncommon breeding populations in the state, no non-breeding occurrences).

Habitat Use and Condition: Black-tailed prairie dogs and Richardson's ground squirrel colonies comprise the primary and secondary habitats of Burrowing Owls in Montana. These species are found exclusively east of the Continental Divide and therefore most confirmed Burrowing Owl breeding records are also east of the Divide (Knowles *In review*). Most Burrowing Owls records from west of the Continental Divide are probably associated with badger-enlarged holes in Columbian ground squirrel colonies (Knowles *In review*).

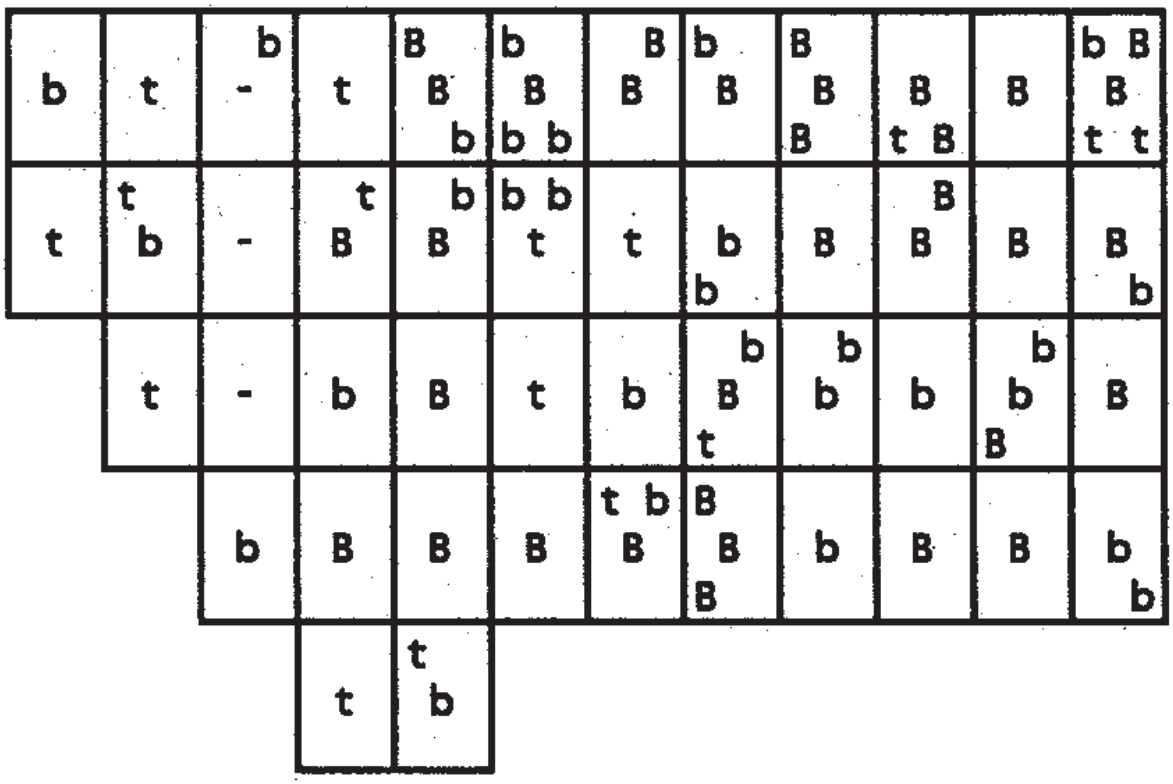

Fig. A-5. Latilong distribution of Burrowing Owls in Montana. B = direct evidence of breeding, b = indirect evidence of breeding, t = species observed, but no evidence of breeding (Montana Bird Distribution Committee 1996).

Most occupied prairie dog habitat in Custer and Harris Creek watersheds (southeast Montana) was on private land (65%), followed by federal (30%) and state lands (5%) (Restani et al 2001). Average town size was 11.0 ± 1.9 ha and 17.3 ± 5.3 ha on private and public lands, respectively. Fifty-four percent of breeding Burrowing Owls were on private land, 23% on state, and the remaining 23% on federal lands.

On the Charles M. Russell NWR in e. Montana, prairie dogs were limited to 283 ha (700 acres) in 1964 (the end of intensive eradication efforts; B. Haglan, pers. commun.). In 1974 prairie dog acreage was 1,807 ha (4,464 acres) and in 1979 acreage had increased to 2,504 ha (6,185 acres). Prairie dog surveys were conducted on the Refuge in 1983, 1988, 1993, and 1997, but data were not reported (Knowles *In review*).

Montana's prairie dog population has declined by 90% or more the 20th century (Flath and Clark 1986). The loss of prairie dogs due to systematic control resulted in a corresponding decline in Burrowing Owls up through at least 1972 when poisoning by the U.S. Fish and Wildlife Service's Animal Damage Control ended on private and public lands (Knowles *In review*). Approximately half of Montana's remaining prairie dog acreage has been lost during the past decade primarily due to plague (Knowles *In review*). Additional impacts identified for this period included recreational shooting, poisoning, and agricultural land conversions (Knowles *In review*).

Threats: Rodent poisoning, plague, and habitat conversion to cropland have reduced and fragmented prairie dog town habitat in Montana (Flath and Clark 1986). Montana's state agricultural agencies consider prairie dogs vertebrate pests and require systematic suppression (Restani et al. 2001), thereby reducing Burrowing Owl habitat.

Recreational shooting on Montana's prairie dog colonies has the potential to cause direct illegal mortality of Burrowing Owl. Anecdotal data suggests that owls are being shot but the significance of this problem remains undocumented (Knowles *In review*). Restani et al. (2001) found no evidence of Burrowing Owl mortality related to recreational shooting; however, they felt it may disrupted daytime foraging activity of adults. Prairie dog shooting may leave prairie dog carcasses on the surface with significant concentrations of lead, which may be ingested by Burrowing Owls (Knowles *In review*).

Literature Cited:

Atkinson, E. C. 2000. Montana–wide Burrowing Owl Surveys: Description of First Year Results, 1999. Unpublished Report, Marmot's Edge Conservation, Belgrade, Montana.

Flath, D. L., and T.W. Clark. 1986. Historic status of black-footed ferret habitat in Montana. Great Basin Naturalist Memoirs 8:63-71.

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: an agency survey. Pages 3-5 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Knowles, C. J. *In review*. A Review of Burrowing Owl Observations Recorded in Montana 1964-1999. FaunaWest Wildlife Consultants Rept., Boulder, Montana.

Marti, C. D., and J. S. Marks. 1989. Medium-sized owls. Pages 124-133 *in* B. A. Giron Pendleton, editor. Proceedings of the Western Raptor Management Symposium and Workshop, National Wildlife Federation, Washington, DC.

Montana Bird Distribution Committee. 1996. P.D. Skarr's Montana Bird Distribution. 5th edition. Special publication no. 3. Montana Natural Heritage Program, Helena, MT.

Restani, M., L. R. Rau, and D. L. Flath. 2001. Nesting ecology Of Burrowing Owls occupying prairie dog towns In southeastern Montana. Journal of Raptor Research 35:296-303.

Richardson, R., and D. C. Tribby. 1991. Status of the Black-tailed Prairie Dog in the Custer Creek Complex, Big Dry Resource Area, Miles City District. Bureau of Land Management. U.S. Department of Interior, Technical Report.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966-2001. Version 2002.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

Wittenhagen, K. W., Jr., and D. C. Tribby. 1996. Status of the Black-tailed Prairie Dog in the Custer Creek Complex, Big Dry Resource Area, Miles City District. Bureau of Land Management. U.S. Department of Interior, Technical Report.

Nebraska

Summary: Burrowing Owls regularly nest in the western two-thirds of Nebraska. Loss of prairie habitat and prairie dog declines have reduced available nesting areas, especially in the eastern part of the state (Ducey 1988). James and Espie (1997) estimated 100 to 1,000 pairs of Burrowing Owls in Nebraska in 1992. The population trend was thought to be decreasing due to habitat loss and pesticide use (James and Espie 1997).

BBS: No significant trends were detected for any survey period (Sauer et al. 2002).

CBC: N/A

Atlas: The Burrowing Owl was previously a common breeder throughout Nebraska; however, breeding is now restricted to the western two-thirds of the state where it is most abundant in the Panhandle (Fig. A-6). Rare observations occur in e. Nebraska, primarily during fall migration (Sharpe et al. 2001).

Research/Monitoring In w. Nebraska, breeding Burrowing Owl pairs declined 63% (91 to 34) from 1990-96 (Desmond et al. 2000). Owl numbers and density of active and inactive prairie dog burrows declined linearly between 1990-96. There was a time-lag in Burrowing Owl response to changes in burrow densities on several prairie dog colonies (Desmond et al. 2000).

Productivity from 1989-93 was low with 1.9 ± 0.1 fledglings/nest (Desmond et al. 2000). Few within-colony variables related to fledging success and a significant colony effect in all five years of productivity study indicated that factors influencing fledging success were at the colony scale. Predation by badgers was significantly lower in high density prairie dog colonies in three of seven years. In one of two years examined, successful nests had an average of 96 active prairie dog burrows within 75 m and unsuccessful nests had only 26 active burrows. This disparity in nesting success may be from enhanced detection of predators by prairie dogs, a dilution effect with abundant alternate prey, reduced vegetation height allowing increased visibility of predators, or presence of alternate burrows for brood dispersal (Desmond et al. 2000).

In w. Nebraska (Banner, Box Butte, Morrill, Scotts Bluff and Sioux counties) Desmond and Savidge (1996) found 85 Burrowing Owl nests in 1989, 109 in 1990, and 103 in 1991. More Burrowing Owls were found in prairie dog communities than in areas with only badger burrows for nesting. Burrowing Owl densities declined between 1989-91 in small prairie dog colonies (<35 ha), but were relatively constant in large colonies (≥ 35 ha). As an indication of density and distribution, nearest-neighbor distance averaged 125 ± 5 m (n = 105, range 46–229 m) for Burrowing Owl nest clusters in large prairie dog colonies. Mean nearest-neighbor distance in small colonies was 105 ± 7 m (n = 118, range 11–434 m) and 240 ± 39 m (n = 20, range 58–588 m) for Burrowing Owls nesting in badger burrows.

Desmond and Savidge (1996) found that Burrowing Owl densities were inversely related to prairie dog town size, active burrow density, inactive burrow density, and total burrow density for at least one of the three years of study. This suggested that burrow availability was not a limiting factor for Burrowing Owls on prairie dog colonies, but they did note that nest sites may be limiting in pastures with only badger burrows. Total Burrowing Owl numbers were positively related to prairie dog town size, but were not related to active, inactive, or total prairie dog burrow densities (Desmond and Savidge 1996). Thus, prairie dog town size, rather than numbers of burrows, was important in determining owl densities and numbers in western Nebraska.

Desmond et al. (1995) hypothesized that if gregarious nesting by Burrowing Owls in prairie dog towns was a response to limited habitat, owl nests should be randomly or regularly distributed throughout the towns with nearest neighbor distance positively related to town size. Alternatively, given sufficient space and burrows, they felt that Burrowing Owls should exhibit a nonrandom spatial nesting pattern. Desmond et al. (1995) found random distributions for Burrowing Owl nests at densities of ≥ 0.22 nests/ha which related to prairie dog towns <35 ha in size. Conversely, Burrowing Owls at densities ≤ 0.20 nests/ha had clumped distributions (with only one exception) and were related to prairie dog towns ≥ 35 ha in size. Within small towns, the nearest neighbor distance between Burrowing Owl nests was positively related to town size; however, this relationship did not occur in large towns. Clumping did not appear to be related to prey abundance or precipitation rates since the spatial patterns of Burrowing Owl nests were similar across the years of study while environmental factors changed. These findings suggest that habitat was limiting on small prairie dog towns and the random distribution was a function of minimum space requirements by Burrowing Owls. Habitat did not appear to be limiting on prairie dog towns ≥ 35 ha, as evidenced by lower Burrowing Owl density, clumped distributions, and unoccupied areas of apparently suitable burrows (Desmond et al. 1995). This research further suggested that additional limiting factors, beyond burrow availability, are influencing Burrowing Owl populations in Nebraska, and perhaps elsewhere.

In w. Nebraska, Burrowing Owl chicks preferred to use active versus inactive prairie-dog burrows for satellite burrows (Desmond et al. 1995). The authors cited burrow maintenance by prairie dogs as the primary benefit; inactive burrows degraded quickly (1-3 yrs) and were unsuitable for Burrowing Owls. Family groups used 10 ± 1 (range 0-36) satellite burrows within 75 m of the nest. Twenty-nine broods preferred active satellite burrows, two broods used active burrows less than expected (both were in

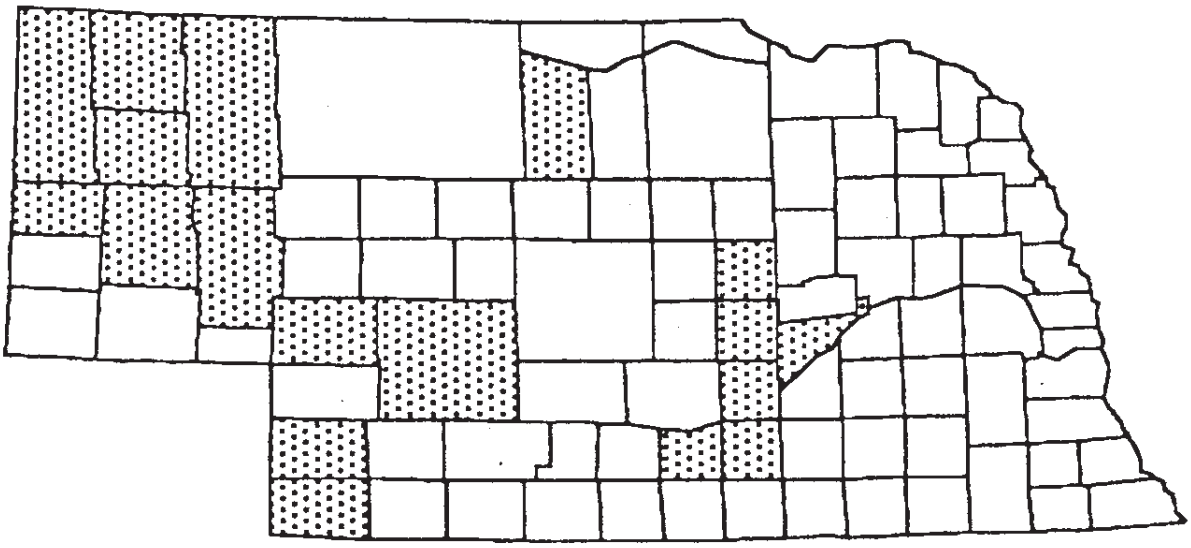

Fig. A-6. Distribution of Burrowing Owls in Nebraska, based on breeding evidence post-1960 (Ducey 1988).

areas with few active burrows due to poisoning), and 11 broods used active burrows in proportion to their availability. Furthermore, seven of the later category had nearly 100% of satellite burrows in active prairie dog burrows. Nine nest burrows had no active prairie-dog burrows within 75 m of the nest (Desmond et al. 1995).

Desmond et al. (1995) found that prairie dog activity in the vicinity of Burrowing Owl nests strongly influenced nest success and attributed this to predator avoidance through prairie dog alarm calls and the "dilution effect" where predators were more likely to target prairie dogs versus the owls. Successful Burrowing Owl nests had more active prairie-dog burrows within a 75-m radius of the nest burrow (Mean = 96 ± 5 m; n = 60) than unsuccessful nests (Mean = 26 ± 4 m; n = 104; Desmond et al. 1995).

Conservation Activities: None identified.

Major Populations: Desmond and Savidge (1996) found 85 Burrowing Owl nests in 1989, 109 in 1990, and 103 in 1991 in 21 prairie dog towns and 17 grassland pastures in Banner, Box Butte, Morrill, Scotts Bluff, and Sioux counties (western Nebraska).

Burrowing Owl surveys were conducted in Banner, Box Butte, Kimball, Morrill, Scotts Bluff and Sioux counties in nw. Nebraska. Of the 92 sites surveyed for prairie dog associates in May/June 2001, 67 contained Burrowing Owls (242 adult Burrowing Owls). Of the 67 Burrowing Owl locations, nine were off-colony sightings and generally only included one or two individuals. In only three of these cases were possible nest burrows observed (all appeared to be old badger or fox dens). The other Burrowing Owls may have been foraging individuals that had ventured far from their nest sites, though three were located in dense sagebrush habitat where ground burrows were difficult to detect (T. VerCauteren, pers. commun.). Sixty-one additional sites (171 individuals) were observed in Cheyenne, Garden, Keith, and Perkins counties by Z. Roehrs, University of Nebraska (T. VerCauteren, pers. commun.). The majority of these sightings were based on road-side counts and do not represent total populations.

State Status: None.

Natural Heritage Rank: G4/S3 (rare and uncommon in the state).

Habitat Use and Condition: Virtually no information was available on habitat condition. A small amount of habitat related research was conducted in western Nebraska by Desmond (1991); however, this thesis focused primarily on spatial relationships within prairie dog towns and badger burrow areas. The author found Burrowing Owls near both agricultural and range habitats. More nests were located in agricultural areas; however, there was no significant difference in numbers or density of Burrowing Owl pairs between the two habitat types.

Threats: Destruction of black-tailed prairie dogs is the primary threat to Burrowing Owls in Nebraska. Black-tailed prairie dog control in Nebraska in 1990-91 accounted for 50% of the reported prairie dog control activity nationwide, and Nebraska state law required prairie dog eradication on public and private lands until 1995 (Roemer and Forrest 1996, Desmond et al. 2000). Desmond and Savidge (1999) documented reduced burrow availability and increased predation rates in prairie dog town subjected to prairie dog control efforts.

Literature Cited:

Desmond, M. J. 1991. Ecological aspects of Burrowing Owl nesting strategies in the Nebraska panhandle. M.S. Thesis, University of Nebraska, Lincoln, NE.

Desmond, M. J., J. A. Savidge, and T. F. Seibert. 1995. Spatial patterns of Burrowing Owl *(Speotyto cunicularia)* nests in black-tailed prairie dog (*Cynomys ludovicianus*) towns in western Nebraska. Canadian Journal of Zoology 73:1375-1379.

Desmond, M. J. and J. A. Savidge. 1996. Factors influencing Burrowing Owl (*Speotyto cunicularia*) nest densities and numbers In western Nebraska. American Midland Naturalist 136:143-148.

Desmond, M. J., and J. A. Savidge. 1999. Satellite burrow use by Burrowing Owl chicks and its influence on nest fate. Pages 128-130 *in* P. D. Vickery and J. R. Herkert, editors. Ecology and conservation of grassland birds of the western hemisphere. Studies in Avian Biology 19.

Desmond, M. J., J. A. Savidge, and K. M. Eskridge. 2000. Correlations between Burrowing Owl and black-tailed prairie dog declines: a 7-Year analysis. Journal of Wildlife Management 64:1067-1075.

Ducey, J. E. 1988. Nebraska Birds, Breeding Status and Distribution. Simmons-Boardman Books, Omaha, Nebraska.

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: an agency survey. Pages 3-5 *in* J. Lincer and K. Steenhof, editors The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Roemer, D. M., and S. C. Forrest. 1996. Prairie dog poisoning in Northern Great Plains: an analysis of programs and policies. Environmental Management 20:349-359.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966-2001. Version 2002.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

Sharpe, R. S., W. R. Silcock, J. G. Jorgensen. 2001. Birds of Nebraska: Their Distribution and Temporal Occurrence. University of Nebraska Press, Lincoln, Nebraska.

Nevada

Summary: Burrowing Owls breed throughout Nevada in salt desert scrub, Mojave shrub, and some sagebrush habitat, as well as in agricultural landscapes. It winters most frequently in the southern half of Nevada, but has been recorded throughout the state during all months (Herron et al. 1985). Local declines are noted where habitat is lost to development at the suburban fringe. For example observations suggest a decline of up to 50% in the Lahontan Valley since 1946 (Alcorn 1988). The statewide population was roughly estimated at 1,000 to 10,000 pairs in 1992, based on a survey of state wildlife agencies in 1992 (James and Espie 1997).

BBS: No significant trends were detected for any survey period (Sauer et al. 2002).

CBC: N/A. This species rarely winters in n. Nevada and sparingly in the s. part of the state.

Atlas: Confirmed or suspected breeding in nearly every county (Fig. A-7, Nevada Breeding Bird Atlas, unpublished data, T. Floyd, pers. commun.). No Atlas records for Mineral, Esmeralda, Douglas, Carson City, or Storey counties.

Research/Monitoring Burrowing Owls were intensively monitored on the Nevada Test Site (NTS) in sc. Nevada from 1996-2001 (Hall et al. *In review*, Steen et al. 1997). Three main ecoregions are recognized on the NTS: Great Basin Desert (Great Basin), Mojave Desert (Mojave), and a transitional ecoregion between the two deserts (transition). A total of 114 Burrowing Owl locations, including 84 burrowing sites and 30 sighting locations, were documented on the NTS for a density of 2.4 Burrowing Owls burrows/100 km^2. Sixty-two locations (54%) occurred in the transition, 37 (33%) occurred in the Mojave, nine (8%) occurred in the Great Basin, and six (5%) were at historic, unspecified locations. Most of the locations occurred in areas with disturbances containing partially buried metal culverts and pipes, relatively deep washes with defined banks, mounds of dirt or excavations, or roadcuts.

A total of 19 nest burrows were documented using camera systems from 1999-2001. Breeding was detected during at least one of the three years at 15 sites (10 in transition, 3 in Mojave, two in Great Basin). Breeding during two of the three years occurred at three sites (two in transition, one in Great Basin), and at one site (transition) breeding occurred during all three years. Nest burrows were predominately in metal culverts or metal or plastic pipes. Two nest burrows were in washbanks, two in man-made dirt mounds, two in roadcuts, and one in a desert tortoise burrow (Hall et al. *In review*, Steen et al. 1997).

A total of 26 breeding pairs and 122 young were detected over the three-year period. Seven, eight, and 11 breeding pairs and 24, 43, and 55 young were detected during 1999, 2000, and 2001, respectively. The average number of young per breeding pairs during the entire period was 4.7 (s.d. = 2.0, n = 26). The average number of young per breeding pair by year was 3.4 (s.d = 1.6, n = 7), 5.6 (s.d. = 1.6, n = 8), and 5.0 (s.d. = 2.1, n = 11) during 1999, 2000, and 2001, respectively. The average number of young per breeding pair by ecoregion was 5.0 (s.d. = 1.8, n = 19), 4.5 (s.d. = 3.1, n = 4), and 3.0 (s.d. = 0, n = 3) in the transition, Great Basin, and Mojave, respectively. Twelve (42%) nesting burrows produced young during two or more years between 1999 and 2001. There appeared to be a relationship between the number of young per breeding pair and the amount of precipitation received during the previous October to March. Young were detected between mid-May and early-September. The local population trend appears to be stable. The increase in number of breeding pairs is due to finding new burrows over the three years and does not necessarily reflect a true increase in the population (Steen et al. 1997, Hall et al. *In review*).

Most of the known Burrowing Owls were monitored at least monthly November 1997–July 1998 and November 1998–December 2001. Burrowing Owls were found on the NTS year-round. Generally, Burrowing Owls wintered on the NTS in low numbers with a large influx around mid-March. Owl numbers fluctuated slightly during the spring and summer, increased slightly during September-October, and then steadily declined through late fall and early winter until they reached their lowest point, usually in January (Steen et al. 1997, Hall et al. *In review*).

Burrowing Owls on the NTS appeared to be quite tolerant of disturbance as measured by traffic counters and flushing distance to observers on foot and in a vehicle. Burrowing Owls successfully produced young with few to many vehicles (<1 to 488 per day) passing withing 10 to 269 m of a nest burrow. No apparent relationship was evident between the number of vehicles per day or distance to road and the number of young. Average flushing distance was approximately 31 m (n = 130) to an observer on foot and approximately 29 m (n = 79) to a vehicle (Steen et al. 1997, Hall et al. *In review*).

The Las Vegas Field Station of the U.S. Geological Survey, Biological Resources Division, in cooperation with the National Park Service will initiate a research study on Burrowing Owls at the Lake Mead National Recreation Area (NRA) in s. Nevada, scheduled to begin in 2002. The objective of the study is to determine distribution and abundance of Burrowing Owls inhabiting the Lake Mead NRA, to relate population abundance to environmental variables on a landscape scale to determine area of high to low Burrowing Owl densities, and evaluate reproductive success in relation to habitat and environmental variables (R. Williams, pers. commun.).

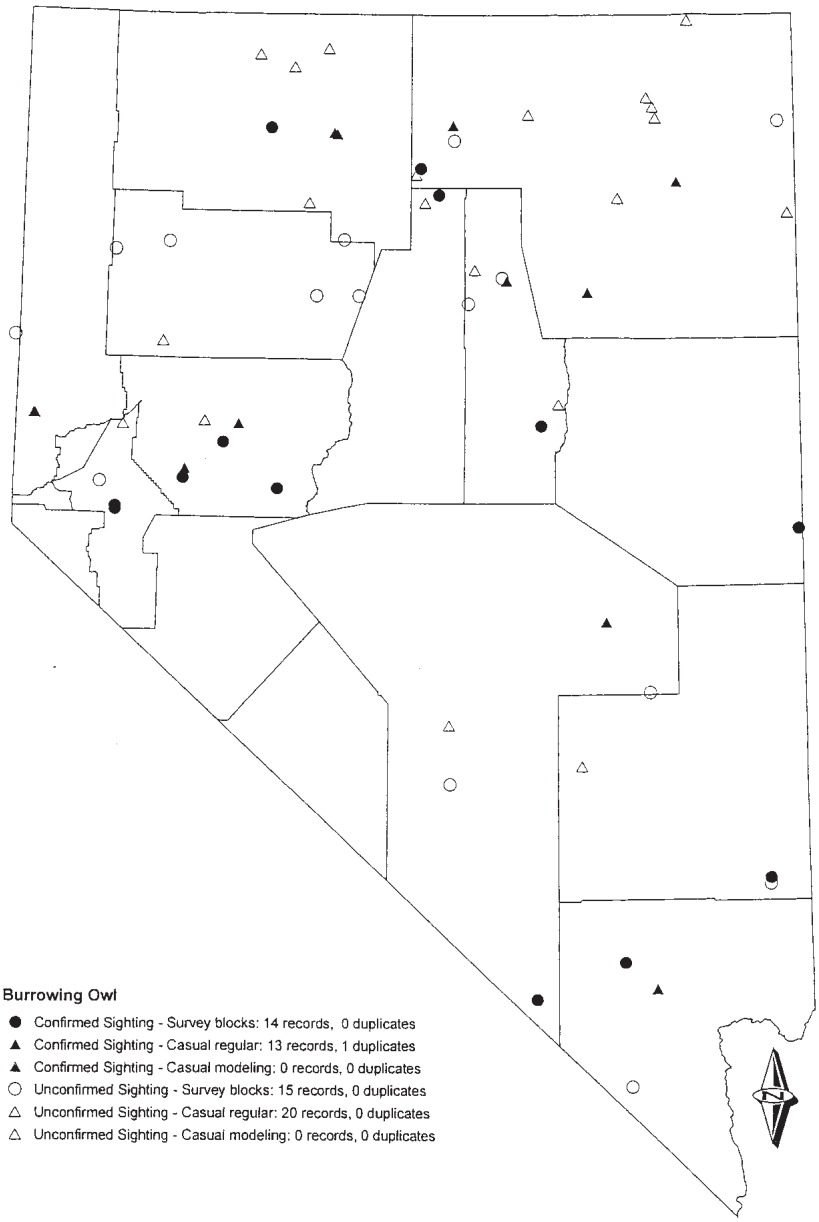

Fig. A-7. Distribution of Burrowing Owls in Nevada from the Nevada Breeding Bird Atlas project (Unpubl. data).

Conservation Activities: The Nevada Partners in Flight Bird Conservation Plan (Neel 1999) outlines conservation measures to improve conditions for Burrowing Owls in the State, and establishes a population objective, to stabilize Burrowing Owl populations by 2004, in each of the 3 habitat types used by Burrowing Owls in Nevada: Agricultural Landscapes, Mojave Scrub, and Salt Scrub.

The Nevada Breeding Bird Atlas proposes to predict the range and breeding locations of Burrowing Owls based on currently known breeding locations and on the distributions of vegetation types within the State. These projections may be used for conservation planning and, with ground-truthing, lead to further investigations of specific habitat conditions favorable for owls.

Major Populations: A total of 114 Burrowing Owl locations, including 19 nest burrows occurred on the NTS in sc. Nevada.

State Status: Species protected under Nevada Revised Statutes 501 and Nevada Administrative Code 503.

Natural Heritage Rank: G4/S3B (rare and uncommon breeding populations in the state).

Habitat Use and Condition: In Nevada, sparsely-vegetated habitats preferred by Burrowing Owls are predominantly found in the salt desert scrub habitat type, which occupies roughly 8.9 million hectares of valley bottoms within the Great Basin physiographic region. Sagebrush habitat was also occupied when artificial burrows were placed in moderately dense sagebrush communities. Burrowing Owls often breed around the fringes of agricultural lands and use crop and pasture lands for foraging during the breeding season. General habitat condition in many of the known nesting territories is poor. Excessive grazing by large ungulates does not seem to decrease nest site suitability, and may be preferred because of increased visibility. Burrowing Owls also nest in open urban areas with open space (e.g., golf courses, airport runways, and industrial areas) if burrows are available. Concrete slabs and other debris left at the old Stead Air Force Base north of Reno, inhabited by California ground squirrels, provided high density nesting habitat for over 40 years (Neel 1999).

Habitat condition of salt desert scrub varies with grazing and fire history. Indian ricegrass was likely much more prevalent historically in this habitat than it is today, and is an important plant for kangaroo rats, a key component in the ecology of this habitat and a prey item for Burrowing Owls. Indiscriminate livestock grazing over the 100-year period following European settlement has tipped the balance toward more durable shrubs, unpalatable forbs, and exotic annual grasses on vast tracts of salt desert scrub. Invasion of exotic plants such as cheatgrass, halogeton, Russian thistle, and in certain places, tamarisk has compromised native communities (Neel 1999). The effect of this type of habitat conversion on Burrowing Owls has not been measured.

Threats: In general, habitat loss is occurring due to agricultural cultivation and development. Development has placed nesting Burrowing Owls under increasing pressure near Reno, Carson City, and Minden-Gardnerville in particular (Neel 1999). Loss of native components and invasion of exotics in Nevada's shrub habitats may have negative implications for Burrowing Owls (see Habitat Use and Condition).

Literature Cited:

Alcorn, J. R. 1988. The Birds of Nevada. Fairview West Publishing, Fallon, Nevada.

Hall, D. B., P. D. Greger, and A. V. Housewright. *In review*. Burrowing owl ecology on the Nevada Test Site. DOE/NV/11718–701. U.S. Department of Energy, National Nuclear Security Administration, Nevada Operations Office, Las Vegas, Nevada.

Herron, G. B., C. A. Mortimore, and M. S. Rawlings. 1985. Nevada Raptors: Their biology and management. Nevada Department of Wildlife.

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: An agency survey. Pages 3-5 in J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Reserarch Report Number 9.

Neel, L. 1999. Nevada Partners in Flight Bird Conservation Plan. Nevada Partners in Flight. http://www.blm.gov/wildlife/plan/pl-nv-10.pdf

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966–2001. Version 2002.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

Steen, D. C., D. B. Hall, P. D. Greger, and C. A. Wills. 1997. Distribution of the chuckwalla, western burrowing owl, and six bat species on the Nevada Test Site. DOE/NV/11718–149. U.S. Department of Energy, Nevada Operations Office, Las Vegas, Nevada.

New Mexico

Summary: Burrowing Owls are found in Great Basin shrub-steppe with open to dense stands of shrubs and low trees, including big sagebrush, saltbush, greasewood, or creosote bush. They are also found in Chihuahuan Desert scrub with open stands of creosote bush and large succulents, Mojave Desert scrub, annual grassland, and farms (New Mexico Dept. Game and Fish 2000). Numerous anecdotal accounts of distribution and relative abundance exist for New Mexico, but no quantitative data are available other than on small study sites. Based on a survey of biologists, James and Espie (1997) estimated 1,000 to 10,000 pairs in New Mexico in 1992 with a stable population trend.

BBS: A significant decline (Trend = –3.8, P <0.03, n = 6) was detected for the 1966-1979 subinterval. No other significant trends were detected. Moderate data deficiencies were noted (sample sizes <14, sub-interval trends significantly different from each other) (Sauer et al. 2002).

CBC: Detected on only three CBCs with regularity, with the largest numbers recorded at Las Cruces, the primary wintering area in the state. No detectable trend (Sauer et al. 1996), although local declines have been noted on the Roswell CBC, due probably to the elimination of a sizeable prairie dog town in that area.

Atlas: Commenced in 2000. Data not yet available.

Research/Monitoring: Botelho and Arrowood (1996) found Burrowing Owl pairs nesting in human-altered areas had significantly more nestlings and fledged significantly more young than pairs nesting in natural areas. They speculated that lower reproductive rates of natural-area pairs was due to increased inter-owl disturbance and/or to increased predation (Botelho and Arrowood 1996).

In 1996-97, Johnson et al. (1997) also found a predominance of nests in areas of heavy human activity on Holloman Air Force Base. Owls were attracted to these areas for a variety of reasons, including soil disturbance and insect-attracting lighting. They found 18 nest burrows in 1996 and 19 in 1997, for a total of 37 nests; 21 in areas of high disturbance and 11 in areas of low disturbance (five nests were not included in the analyses due to reoccupancy). The mean number of young fledged from all successful nests was 2.1 (range 1-4) in 1996 and 2.7 (range 1-5) in 1997. Nest success was 64% (n = 11) for 1996 and 77% (n = 13) for 1997. Nests in high disturbance areas were closer to high perches, closer to roads, further from shrubs, and had lower shrub cover than nests in low disturbance areas. Despite a preference to breed in these areas, and contrary to the findings of Botelho and Arrowood (1996), high rates of abandonment were noted in disturbed areas. Sixty-four percent of nests disturbed by human activity or natural events were abandoned. Of 11 nests disturbed by human activity alone, 55% (6) were abandoned (Johnson et al. 1997). Forty-five artificial burrows were installed on Holloman Air Force Base in 2000-2001 to replace natural burrows that had collapsed (C. Finley, pers. commun.).

Martin (1973) studied 15 breeding pairs of Burrowing Owls three miles south of Albuquerque, NM, in the Tijeras Arroyo and a railway cut in desert grassland. Burrowing Owls exclusively used rock squirrel burrows since no prairie dogs were present in the study area. Mean reproductive success was 4.9 young per pair. The lowest possible mean clutch size was 5.2 eggs based on 78 young seen.

Martin (1973) banded nine breeding males and nine females in 1970. Six males and two females returned in 1971. All returning males selected the same burrow they had inhabited in 1970, unless the burrow had been destroyed. Of banded birds, no pair combinations were retained in 1971, suggesting low intra-pair fidelity. It was unknown whether low female return rates were due to higher mortality or to lower site fidelity. Martin (1973) determined that few Burrowing Owls remained resident on the study area during winter. Fall departure was from August through September and earliest spring arrival was mid-March. Pair formation in some Burrowing Owls apparently occurred before arrival.

Hawks Aloft, Inc. has been monitoring breeding success in nests on Kirtland Air Force Base in Albuquerque since the late 1990's. Numbers declined significantly in 2000 and 2001 for unknown reasons (C. Finley, pers. commun.). Monitoring is continuing.

On Holloman Air Force Base, six of 18 (33%) nesting burrows were occupied by Burrowing Owls during the winter, in addition to two newly occupied winter burrows (Johnson et al. 1997). Similarly, most males and a few female Burrowing Owls overwinter at burrows they used for breeding on the campus of New Mexico State University in Las Cruces (Arrowood et al. 2000), while all fledglings leave the area. Few banded owls ever return to the study area. However, some owls return after several years of absence.

Arrowood et al. (2000) found that resident male Burrowing Owls produced more nestlings (mean = 3.5 ± 2.6) than migrant males (mean = 2.5 ± 1.9). Area-experienced females produced more nestlings than area-inexperienced females (mean = 2.2 ± 2.3). More nestlings were produced by resident males paired with area-experienced females than were produced by other pair types. Most females were migratory, although it is unknown what factors influence females to overwinter or to migrate.

Arrowood et al. (2001) reported that in some areas of New Mexico, Burrowing Owl populations were stable or increasing, although decreasing populations were reported in other areas. Stable and increasing populations were associated with the presence of suitable habitat and increased precipitation and food availability. Decreasing populations were associated with loss of suitable habitat, due to declining prairie dog populations and urban sprawl.

Conservation Activities: The New Mexico Burrowing Owl Working Group (NMBOWG) was formed in response to population declines at some sites in New Mexico (Hawks Aloft, Inc. 2002). The NWBOWG is a collaborative effort of non-profit organizations, government agencies, private enterprises and individuals. The goals of the working group are to (1) facilitate communication, (2) establish a statewide monitoring effort, (3) maintain a web page to educate the public, promote the NMBOWG, and provide on-line data forms, (4) promote the NMBOWG through public outreach, (5) develop a review committee to determine sighting accuracy, (6) enter sightings into a database and share the database with contributing organizations, (7) create a map showing general locations in New Mexico, (8) over time, determine the population trends of Burrowing Owls in New Mexico, and (9) develop conservation recommendations based on monitoring results. The NMBOWG currently supports on-going research projects at four sites: Holloman and Kirtland Air Force Bases, New Mexico State University, and the Turner Ranch. The NMBOWG has initiated a volunteer monitoring system to collect data on Burrowing Owl populations in the state (C. Finley, pers. commun., Hawks Aloft, Inc. 2002).

Major Populations: Burrowing Owls have been documented as permanent residents at the White Sands National Monument in Dona Ana and Otero counties (White Sands National Monument 1993), Grulla National Wildlife Refuge (USFWS 1994), Holloman Air Force Base (Mesilla Valley Audubon Society 1996), Gray Ranch in Hidalgo County (Black 1997), and the Las Cruces/New Mexico State University area (W. Howe, pers. commun.). Burrowing Owls are uncommon spring and fall migrants and common breeders at the El Malpais National Monument and National Conservation Area (Hvenegaard 1989), Sevilleta National Wildlife Refuge (USFWS 1992), and Fort Bliss (Fort Bliss Directorate of Environment 1995) (New Mexico Dept. Game and Fish 2000). A minimum of 475 Burrowing Owls were detected in sc. Quay county, Curry county, and n. Roosevelt County in 2002, where 63% of surveyed prairie dog colonies were occupied by Burrowing Owls (L. Sager and C. Rustay, pers. commun.). Kirtland AFB in Albuquerque has one of the largest populations of Burrowing Owls in New Mexico with 40-50 pairs present in some years.

State Status: No special designation.

Natural Heritage Rank: G4/S4B, S4N (widespread, abundant, and secure in the state, but of long-term concern during breeding and non-breeding seasons).

Habitat Use and Condition: The grasslands of southern New Mexico have been invaded by mesquite and creosote bush (Gardner 1951, York and Dick-Peddie 1960), reducing habitat suitability in much of this region.

Best (1969) studied Burrowing Owls in Dona Ana and Luna counties of south-central New Mexico from 1964-67, including nine colonies ranging from 9-19 birds. Burrowing Owls used a broad range of macro and micro-habitats. Single breeding pairs were found in small isolated areas of open habitat, and colonies were restricted to yucca grassland with burrows of banner-tailed kangaroo rats. The largest colonies found during the study were in areas occupied by cattle.

Fire affects Burrowing Owls by altering vegetation and prey base. Frequent fire can maintain or improve Burrowing Owl habitats by reducing plant height and cover around burrows and by controlling woody plant invasion. Periodic fire in grasslands probably increases prey diversity for Burrowing Owls, and may increase overall prey density (New Mexico Dept. Game and Fish 2000).

Threats: Prairie dog eradication, increased urbanization and human disturbance during the breeding season represent primary threats to Burrowing Owls in New Mexico (Arrowood et al. 2001).

Literature Cited:

Arrowood, P. C., C. A. Finley, C. Blood, B. Thompson, and E. S. Botelho. 2000. Residency, return, and reproduction by Burrowing Owls *(Athene cunicularia)* in southern New Mexico, U.S.A. Poster presentation; Owls 2000—The Biology, Conservation, and Cultural Significance of Owls. Australian National University, Canberra, Australia.

Arrowood, P. C., C. A. Finley, and B. C. Thompson. 2001. Analyses of Burrowing Owl populations in New Mexico. Journal of Raptor Research 35:362-370.

Best, T. R. 1969. Habitat, annual cycle, and food of Burrowing Owls in southcentral New Mexico. M.S. Thesis, New Mexico State University, Las Cruces, New Mexico.

Black, C. 1997. Animas Foundation Gray Ranch Bird List. Animas Foundation, Animas, New Mexico.

Botelho, E. S., and P. C. Arrowood. 1996. Nesting success of western Burrowing Owls in natural and human-altered environments *in* Bird, D., D. Varland, and J. Negro, editors. Raptors in Human Landscapes. Academic Press, Ltd., London.

Botelho, E. S., and P. C. Arrowood. 1998. The effect of burrow site use on the reproductive success of a partially migratory population of western Burrowing Owls *(Speotyto cunicularia hypugaea).* Journal of Raptor Research 32:233-240.

Conservation Division, Fort Bliss Directorate of Environment. 1995. Checklist of Birds, Fort Bliss, Texas [and New Mexico].

Hawks Aloft, Inc. 2002. New Mexico Burrowing Owl Working Group web page. http://www.hawksaloft.org/burrowingowl.html.

Hvenegaard, G. T. 1989. A checklist of the birds of El Malpais National Monument a Conservation Area. Southwest Parks and Monuments Association.

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: an agency survey. Pages 3-5 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Johnson, K., L. DeLay, P. Mehlhop, and K. Score. 1997. Distribution, Habitat, and Reproductive Success of Burrowing Owls on Holloman Air Force Base. Unpublished Report, New Mexico Natural Heritage Program.

Martin, D. J. 1973. Selected aspects of burrowing owl ecology and behavior. Condor 75:446-456.

Mesilla Valley Audubon Society. May 1996. Checklist of Birds Holloman Airforce Base.

New Mexico Department of Game and Fish. 2000. Species List / Species Accounts: Burrowing Owl. Biota Information System of New Mexico (BISON-M), New Mexico Department Of Game And Fish, Santa Fe, New Mexico. http://151.199.74.229/states/nmex_main/species/041320.htm (Version 1/2000).

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966-2001. Version 2002.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

U.S. Fish and Wildlife Service. 1992. Birds of Sevilleta National Wildlife Refuge. U.S. Fish and Wildlife Service. http://www.npwrc.usgs.gov/resource/othrdata/chekbird/r2/sevillet.htm (Version 22 May 99).

U.S. Fish and Wildlife Service. 1994. Grulla National Wildlife Refuge. U.S. Fish and Wildlife Service. http://www.npwrc.usgs.gov/resource/othrdata/chekbird/r2/grulla.htm (Version 22 May 98).

White Sands National Monument. 1993. Checklist of Birds.

North Dakota

Summary: Burrowing Owl nesting was documented throughout North Dakota from the 1800s until the 1950s. From approximately 1950 to 1970, the range contracted and the species was no longer found in the eastern one-third to one-fifth of the state. From 1970 to 1999, the range further contracted and Burrowing Owls are currently rare north and east of the Missouri River. Literature reviews indicate no breeding records for e. North Dakota since the 1980s. James and Espie (1997) estimated 100 to 1,000 Burrowing Owl pairs in North Dakota with a stable population trend.

Extensive Burrowing Owl surveys from 1994-99 found very low occupancy rates at historically abundant sites (Murphy et al. 2001). Data sources are very current and reliable for trend information east and north of the Missouri River. West of the Missouri River the population trend is less clear, but is tied to the status of the black-tailed prairie dog, which has decreased significantly in recent decades.

BBS: A significant decline in Burrowing Owl relative abundance was noted for 1980-99 (Trend = –15.8, P <0.00, n = 9). No additional significant trends were detected. Data credibility is low due to small sample sizes and high variance (Sauer et al. 2002).

CBC: N/A.

Atlas: No breeding bird atlas is published for North Dakota. Stewart (1975) stated that Burrowing Owls were fairly common on the Northwestern Drift Plain; uncommon on the Missouri Coteau, Southwestern Slope, and Southern Drift Plain; and rare in the Agassiz Lake Plain and the Northeastern Drift Plain (Fig. A-8).

Research/Monitoring: Igl et al. (1999) compared Burrowing Owl abundance on 128 randomly selected plots (quarter-sections) from 1967 (Stewart and Kantrud 1972) and 1992-93 (Igl and Johnson 1997). Burrowing Owl frequency of occurrence on survey plots (% of plots with owls) did not change over the survey period; frequency was 1.6% in 1976 compared to 2.3% and 1.6% in 1992 and 1993, respectively. The statewide population estimate was 7,000 breeding pairs in 1967 compared to 7,000 and 5,000 pairs in 1992 and 1993, respectively.

Murphy et al. (2001) conducted three different Burrowing Owl surveys throughout much of w. and c. North Dakota between 1994-99. They (1) randomly sampled 20% of two intensive study areas in Divide and Kidder counties, (2) searched for Burrowing Owls within 500 m of 35 historic (1976-87) nesting areas in northwestern North Dakota, and (3) surveyed for Burrowing Owls in prairie dog towns on the Little Missouri National Grassland (LMNG; Billings, Slope, Golden Valley, and McKenzie counties of southwestern North Dakota). They found very few Burrowing Owls in random surveys of Divide County; the maximum density was 3.2 pairs/100 km^2 in 1998. The maximum density based on suitable habitat was 7.2 pairs/100 km^2. Also, no Burrowing Owls were detected during surveys of historic breeding areas throughout nw. North Dakota. They felt the decline in Burrowing Owl abundance in Divide County may be from loss of burrowing animals and grassland habitat. Due to the presence of what appeared to be unoccupied suitable habitat, Murphy et al. (2001) felt that additional factors may also be influencing Burrowing Owl populations in nw. North Dakota. Murphy et al. (2001) failed to locate Burrowing Owls during intensive random surveys of Kidder County in 1998, where the species was fairly common until the 1970s. Area resource staff noted declines in number of breeding Burrowing Owls since the mid-1980s. Burrowing Owls also have disappeared from Ward County in nc. North Dakota.

In 1991, De Smet et al. (1992) found Burrowing Owls at 45% of prairie dog towns surveyed on the LMNG, but felt the occupancy rate was underestimated due to poor survey conditions. Murphy et al. (2001) found Burrowing Owls at 39% of the same towns which were still active in 1996. Additionally, Burrowing Owls were detected on <50% of prairie dog towns during other spring and summer surveys (1998) reported in Murphy et al. (2001), despite anticipated higher detection rates for summer surveys

Murphy et al. (2001) also selected 10 prairie dog towns which had been documented as occupied by Burrowing Owls in 1991 (De Smet et al. 1992) for reoccupancy surveys in 1995-98. They found 5-7 of these were used by Burrowing Owls annually, and all but one town were occupied for more than one year. Higher occupancy rates of recently used prairie dog towns (<5 yr) indicate short-term site fidelity for the species. Non-use of available habitat within years may suggest the Burrowing Owl is below carrying capacity in North Dakota.

Conservation Activities: A program under the North American Waterfowl Management Plan and Ducks Unlimited exists to permanently protect native prairie through perpetual easements. This has some positive ramifications for Burrowing Owl habitat conservation but overlooks some important, historical owl habitats (R. Murphy, pers. commun.).

The U.S. Forest Service expects to implement a proposed Land and Resource Management Plan in the near future. The preferred alternative currently includes objectives to double prairie dog town acreage and protective measures for Burrowing Owl nest sites (D. Freed, pers. commun.).

North Dakota Game and Fish Department has solicited funding for compiling Burrowing Owl nesting records and provided financial assistance for the research conducted in Murphy et al. (2001) and to the Canadian Wildlife Service for a Burrowing Owl migration telemetry project (R. Murphy, pers. commun.).

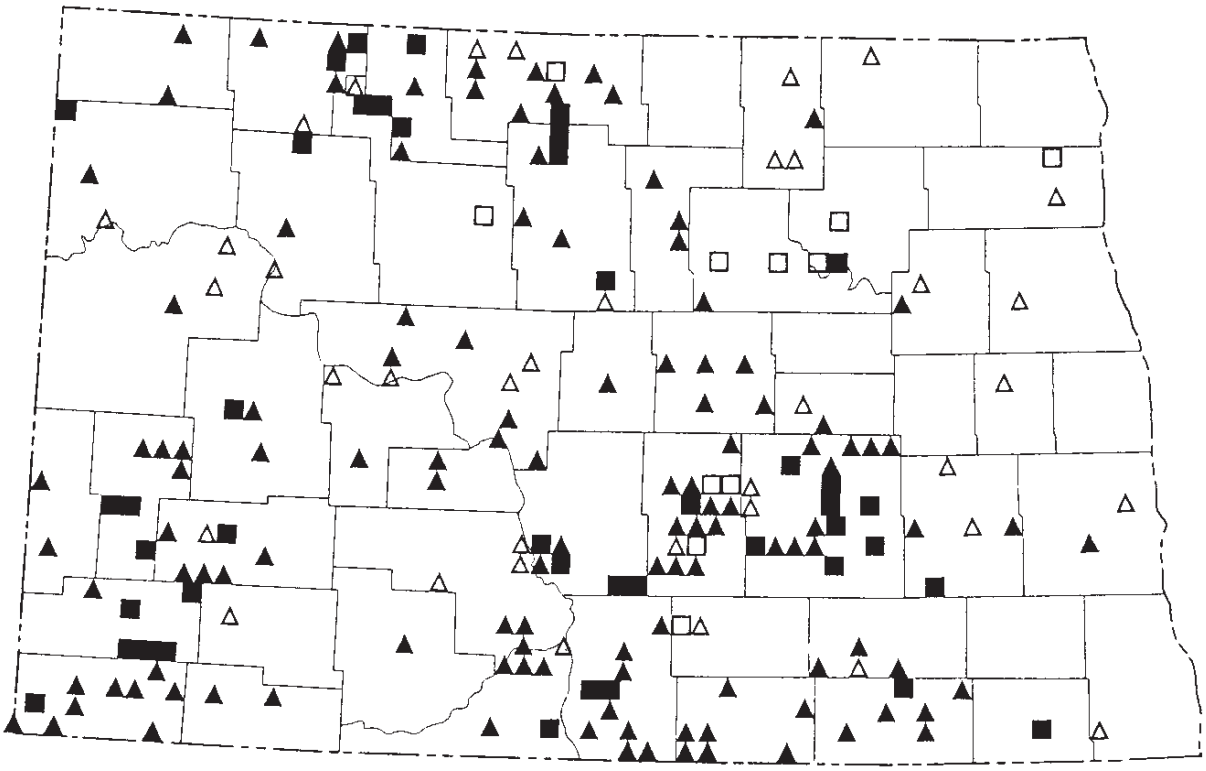

Fig. A-8. Distribution of Burrowing Owls in North Dakota, prior to 1972. Filled squares = nest or dependent young recorded from 1950 to 1972. Empty squares = nests or dependent young recorded prior to 1950. Filled triangles = territorial males or pairs recorded from 1950 to 1972. Empty triangles = territorial males or pairs recorded prior to 1950 (Stewart 1975).

Major Populations: Population estimate on the LMNG was 82 breeding pairs in 1999 (D. Freed, unpubl. data). Major populations also occur on tribal lands in Sioux County (Murphy et al. 2001).

State Status: No official state list for North Dakota.

Natural Heritage Rank: G4/SU (unrankable, possibly in peril in the state, but status not certain).

Habitat Use and Condition: Overall, about 75% of North Dakota mixed-grass prairie has been lost, primarily to agricultural cropland, with decreases being particularly great in the Drift Plain, the largest physiographic subregion in North Dakota (Samson and Knopf 1994, Murphy et al. 2001). Conversion of native prairie continues along with invasion of introduced and woody vegetation (Samson and Knopf 1994, Murphy et al. 2001). Burrowing Owls no longer occur on National Wildlife Refuges in North Dakota (Murphy et al. 2001) due to refuge management practices favoring tall, dense vegetation (Murphy 1993).

Burrowing Owls are closely associated with tracts of mixed-grass prairie that are heavily grazed by both livestock and prairie dogs. Burrowing Owls concentrate in grasslands with colonies of burrowing mammals, particularly colonies of black-tailed prairie dogs west of the Missouri River and colonies of Richardson's ground squirrels elsewhere (Stewart 1975). Murphy et al. (2001) felt the decline in Burrowing Owl abundance in w. North Dakota may be from loss of burrowing animals and grassland habitat. Native prairie around historic Burrowing Owl nest sites declined 33% in Divide County since the 1960s, from 15.5 ± 2.5 (SE) ha within 500 m of nests in 1969 to 9.5 ± 2.2 ha in 1998. Loss of breeding Burrowing Owls in c. North Dakota may be linked to declines in Richardson's ground squirrels, the primary burrow provider in this region. Murphy et al. (2001) seldom observed Richardson's ground squirrels, burrows, or heavily grazed native prairie in and near Kidder County. They felt ground squirrel abundance was negatively influenced by increased vegetation height in recent years (1993-99).

In sw. North Dakota, the black-tailed prairie dog is largely restricted to the LMNG and tribal lands in Sioux County. The remaining area is dominated by agriculture with few active towns. Acreage of prairie dog towns decreased 93% from 1939-72 in and near the LMNG (from 5,512 ha to 403 ha; Bishop and Culbertson 1976); and currently occupies only 0.2% of LMNG (Murphy et al. 2001). Acreage of prairie dog towns on the LMNG is believed to be stable to increasing slightly, while the status of prairie dog habitat outside the LMNG is unknown (D. Freed, pers. commun.). Prairie dogs are, however, considered a noxious pest in North Dakota and private landowners are required to eradicate them (North Dakota Century Code 63-01.1-02, subsec. 12; Murphy et al. 2001).

Threats: Loss of habitat is the primary threat to Burrowing Owls in North Dakota. Recent declines in Richardson's ground squirrels in c. and e. North Dakota may be influencing Burrowing Owls populations. Murphy et al. (2001) noted decreases in ground squirrel abundance coinciding with increased vegetation height in Kidder County (c. North Dakota). Livestock ranching, especially sheep grazing, has decreased in some east river counties in recent years. Burrowing Owl habitat quality is probably declining in part due to these changes. Large-scale plague events in prairie dog populations may result in long-term habitat loss for Burrowing Owls (D. Freed, unpubl. data).

Predation on Burrowing Owls has been exacerbated by increases in numbers of Red-tailed Hawks and Great Horned Owls due to increases in trees because of succession, shelter-belt planting, and fire suppression (Clayton and Schmutz 1999, Murphy 1993). Mammalian predation pressure likely has increased due to fragmentation of habitat and major change in composition and distribution of predator communities (Sargeant et al. 1993, Murphy et al. 2001).

Literature Cited:

Bishop, N. G and J. L. Culbertson. 1976. Decline of prairie dog towns in southwestern North Dakota. Journal of Range Management 29:217-220.

Clayton, K. M. and J. K. Schmutz. 1999. Is the decline of Burrowing Owls (*Speotyto cunicularia*) in prairie Canada linked to changes in Great Plains ecosystems? Bird Conservation International 9:163-185.

De Smet, K. D., G. Mcmaster, and K. Mazur. 1992. Cooperative surveys and reintroductions of Burrowing Owls between Manitoba and North Dakota, 1991. Manitoba Natural Resource Report.

Igl, L. D., D. H. Johnson. 1997. Changes in breeding bird populations in North Dakota: 1997 to 1992-93. Auk 114:74-92.

Igl, L. D., D. H. Johnson, and H. A. Kantrud. 1999. Uncommon breeding birds in North Dakota: population estimates and frequencies of occurrence. Canadian Field Naturalist 113:646-651.

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: an agency survey. Pages 3-5 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Murphy, R. K. 1993. History, nesting biology, and predation ecology of raptors in the Missouri Coteau of northwestern North Dakota. Ph.D. Dissertation, Montana State Univ., Bozeman, Montana.

Murphy, R. K., K. W. Hasselblad, C. D. Grondahl, J. G. Sidle, R. E. Martin, and D. W. Freed. 2001. Status of the Burrowing Owl in Minnesota. Journal of Raptor Research 35:322-330.

Samson, F., And F. Knopf. 1994. Prairie conservation in North America. Bioscience 44:418-421.

Sargeant, A. B., R. J. Greenwood, M. A. Sovada, and T. L. Shaffer. 1993. Distribution and abundance of predators that affect duck production—Prairie Pothole Region. U.S. Fish and Wildlife Service Resource Publication 194.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966-2001. Version 2002.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

Stewart, R. E. 1975. Breeding Birds of North Dakota. Tri-College Center For Environmental Studies, Fargo, North Dakota.

Stewart, R. E., and H. A. Kantrud. 1972. Population estimates of breeding birds in North Dakota. Auk 89:766-788.

Oklahoma

Summary: Burrowing Owls in Oklahoma occur primarily in association with prairie dog towns in short- and mixed-grass prairies and mesquite savannahs in the w. third of the state and are primarily restricted to the panhandle (Sheffield and Howery 2001). During the breeding season some owls are found away from prairie dog towns in shortgrass prairie. Burrowing Owls occasionally winter in w. and c. Oklahoma in the vicinity of prairie dog towns, airports, and areas with short grass (Sheffield and Howery 2001). Based on a survey of biologists, James and Espie (1997) estimated 100 to 1,000 pairs in Oklahoma with a stable population trend. Sheffield and Howery (2001) estimated a breeding population of 800-1000 individuals in the state.

BBS: A significant negative trend was noted for 1966-2001 (Trend = –11.5, P <0.00, n = 10). No other significant trends were detected. Data credibility is low due to small sample sizes and high variance (Sauer et al. 2002).

CBC: N/A; <1% of the summer population remains resident during the winter in Oklahoma.

Atlas: Unknown

Research/Monitoring: In Beaver and Texas counties on the Oklahoma panhandle, Butts and Lewis (1982) found 66% (n = 359) of adult owls were associated with prairie dog colonies even though this habitat comprised only 0.16% of the study area. This was equivalent to a density of 0.52 Burrowing Owls/ha or 1 pair/1.9 ha. The estimated population outside 1.6 km from prairie dog colonies was 92 pairs (34%; 0.0002 Burrowing Owls/ha or 1 pair/4,604 ha). The average brood size was 4.7 (range 2-9, n = 54) and nest success was 79%. Survival of young owls from the fledgling stage through July was 89% (n = 38) (Butts 1971). Most of this population migrated from Oklahoma in October; about 0.05% of the total population remained resident (Butts and Lewis 1982). In a survey of prairie dog colonies and their associated vertebrates in Oklahoma, Shackford and Tyler (1991) recorded at least one Burrowing Owl on at least one prairie dog colony in every county with ≥ 7 prairie dog colonies (n = 11), but no Burrowing Owls in any county with ≤ 2 prairie dog colonies (n = 10).

Currently there are no on-going research projects in Oklahoma which specifically target Burrowing Owls. A project is underway to monitor prairie dog town numbers, acreage, and distribution and could potentially also address Burrowing Owls (M. Howery, pers. commun.).

Conservation Activities: The USFWS attempted reintroduction of Burrowing Owls to a prairie dog town on the Wichita Mountains National Wildlife Refuge. The reintroduction effort failed to establish a breeding population. An Oklahoma state management plan is currently being developed for the black-tailed prairie dog. The plan could have indirect benefits for the Burrowing Owl (M. Howery, pers. commun.).

Major Populations: Based on BBS data, other breeding records, and personal observations, Sheffield and Howery (2001) estimated the total breeding population in Oklahoma as 800-1,000 individuals. The majority of the breeding individuals are limited to the panhandle counties of Cimmaron, Texas, and Beaver. The wintering range of the Burrowing Owl in Oklahoma is limited primarily to the western half of the state, with periodic extra-limital records further east (Sheffield and Howery 2001).

State Status: Species of Special Concern, Category II (native species identified by technical experts as possibly threatened or vulnerable to extirpation but for which little, if any, evidence exists to document the population level, range, or other factors pertinent to its status).

Natural Heritage Rank: G4/S2 (imperiled in the state because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the state).

Habitat Use and Condition: Beaver and e. Texas counties in the panhandle of Oklahoma had 50-60% of the area cultivated with the remainder used primarily for cattle grazing. Most prairie dog towns were located in linear strips of remaining habitat along drainages (Butts 1971). Butts and Lewis (1982) found 66% (n = 359) of adult owls were associated with these prairie dog colonies even though this habitat comprised only 0.16% of the study area. Within colonies, Burrowing Owl nests were distributed randomly, concentrated along the edges of colonies, and clumped. Nests outside dog towns were in badger dens but never in the more numerous burrows of thirteen-lined ground squirrels, spotted ground squirrels, or Ord's kangaroo rats. Of approximately 300 nests, all but six were in heavily grazed, short grass; the exceptions were five nests on field edges with vegetation clipped short by prairie dogs and one nest in a mowed pasture. Burrowing Owls did not exhibit any preference for soil type. Eradication of prairie dogs resulted in rapid declines in numbers of burrows available (<3 yr), and consequently Burrowing Owls rarely used inactive towns. Burrowing Owls did not nest in areas where prairie dogs were eradicated. Areas with light cattle grazing were used occasionally for feeding and escape. The use of satellite burrows by the male and broods indicated a requirement met only in prairie dog towns (Butts and Lewis 1982). They believed non-prairie dog habitat in Oklahoma was marginal breeding habitat for Burrowing Owls. Prairie dog populations should be maintained if conservation of Burrowing Owls is desired (Butts and Lewis 1982).

Oklahoma historically had millions of hectares of prairie dog towns, but by 1968 this had declined to 3,856 ha (Tyler 1968). Butts (1973) documented a decrease of 7% in acreage and 12% in numbers of active prairie dog towns in his study area (Oklahoma panhandle) from 1967 through 1970. Formation of four new dog towns and a 9.5 % increase in acreage

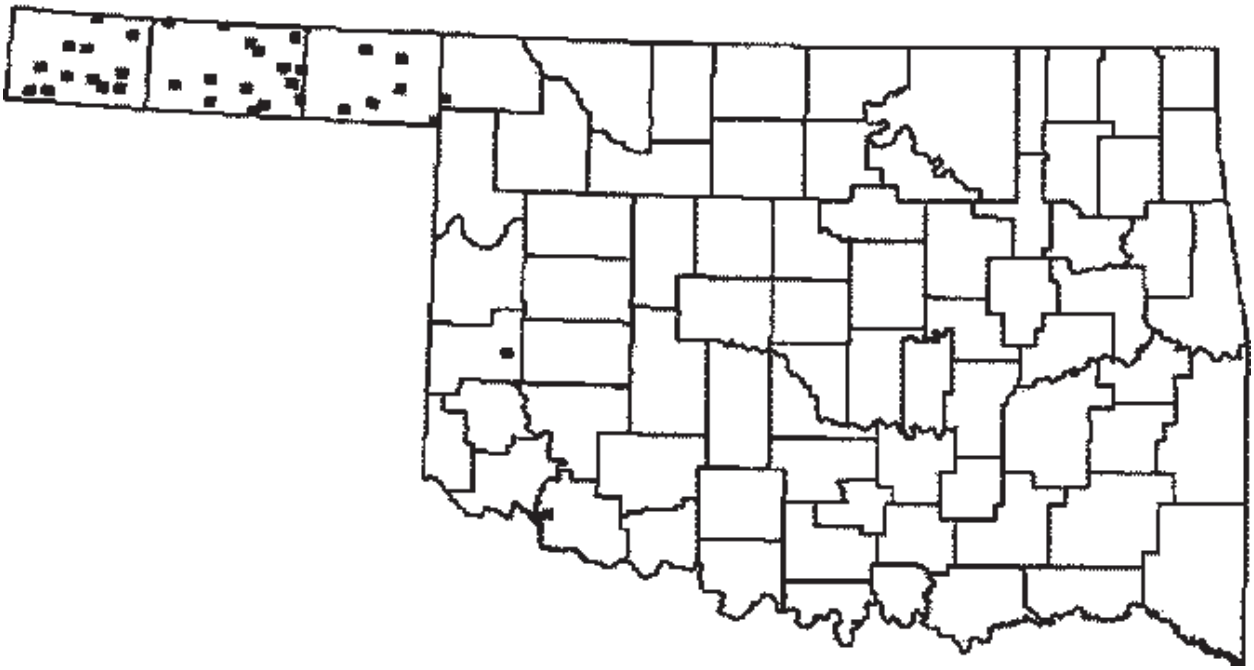

Fig. A-9. Distribution of Burrowing Owls in Oklahoma (Oklahoma Breeding Bird Atlas Project, D. Reinking, pers. commun.).

of existing towns tempered the net loss. Prairie dog eradication generally eliminated or reduced to a few individuals distinct colonies or colony segments (Butts 1973). Conversion of grassland to cropland (especially irrigated cropland) also caused a decrease in the availability and persistence of suitable nest burrows that could have adversely affected owl populations (Butts 1973). Tyler (1968) surveyed prairie dog colonies and associated vertebrates, and approximately 20 years later Shackford and Tyler (1991) repeated the survey. Comparison of the two studies showed a drastic decrease in both prairie dog colonies and Burrowing Owl numbers in the majority of the state (excluding the panhandle).

Threats: Conversion of grassland to cropland (especially irrigated cropland) has caused a decrease in the availability and persistence of suitable nest burrows that could adversely affect owl populations (Butts 1973). Continued habitat loss and loss of prairie dog to plague and direct eradication are also detrimental to Burrowing Owls.

Literature Cited:

Butts. K. O. 1971. Observations on the ecology of Burrowing Owls in western Oklahoma. A preliminary report. Proceedings of the Oklahoma Academy of Science 51:66-74.

Butts, K. O. 1973. Life history and habitat requirements of Burrowing Owls in western Oklahoma. M.S. Thesis, Oklahoma State University, Stillwater, Oklahoma.

Butts, K. O., and J. C. Lewis. 1982. The importance of prairie dog towns to Burrowing Owls in Oklahoma. Proceedings of the Oklahoma Academy of Science 62:46-52.

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: an agency survey. Pages 3-5 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966-2001. Version 2002.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

Shackford, J. S., and J. D. Tyler. 1991. Vertebrates associated with black-tailed prairie dog colonies in Oklahoma. Final Report, Oklahoma Department of Wildlife Conservation, Oklahoma City, Oklahoma.

Sheffield, S. R., and M. Howery. 2001. Current status, distribution, and conservation of the Burrowing Owl in Oklahoma. Journal of Raptor Research 35:351-356.

Tyler, J. D. 1968. Distribution and vertebrate associates of the black-tailed prairie dog in Oklahoma. Ph.D. Dissertation, University of Oklahoma, Norman, Oklahoma.

Oregon

Summary: East of the Cascades, the Burrowing Owl breeds in all or nearly all counties. As it was historically, it is now most common in Wasco, Morrow, Umatilla, Malheur, Harney, and Lake counties (Gabrielson and Jewett 1940, Adamus et al. 2001). West of the Cascades it bred in the Rogue River Valley (Jackson County) until the late-1970's or early 1980's (C. Cwiklinski, pers. commun). It is a rare winter visitor in the Rogue and Willamette valleys, along the coast, and occasionally in e. Oregon (Marshall et al. 1996). The population was estimated to be between 1,000 and 10,000 pairs in 1992 (James and Espie 1997). Burrowing Owl populations are generally thought to be stable in se. Oregon, possibly increasing with conversion of shrub-steppe to annual grasses in Malheur County, but significant trend data is lacking. Habitat loss has been greatest in the Columbia Basin (ne. Oregon) due to cultivation (Marshall et al. 1996).

BBS: No significant trends were detected over any survey period. Data credibility is low due to small sample size and high variance (Sauer et al. 2002).

CBC: Limited data available; rare winter records are from west of the Cascades, mostly interior valleys; some records from the coast.

Atlas: The Oregon Breeding Bird Atlas (Adamus et al. 2001) shows Burrowing Owls breeding throughout three se. counties: Malheur, Harney, and Lake (Fig. A-10). Additionally Burrowing Owls were reported in se. Deschutes and s. Crook counties, between the Wallowa and Blue Mountains in Baker and Union counties and east of the Columbia River Gorge in Wasco, Sherman, Gilliam, Morrow, and Umatilla counties. Breeding has been confirmed in s. Klamath County west of the Cascades, and Linn County. At this site, a pair was seen entering a burrow over the course of several weeks, but neither eggs nor chicks were observed and the birds did not return in subsequent years (P. Adamus, pers. commun.). Another summer sighting of a single individual on a culvert in this county suggests that Burrowing Owls might be re-established west of the Cascades if proper habitat conditions existed.

Research/Monitoring: In nc. Oregon (Gilliam, Morrow, and Umatilla counties) Burrowing Owl nest success was 57% for 63 nests in 1980 and 50% for 76 nests in 1981. Desertion was the major cause (32%; 45/139 nesting attempts) of nest failures and was related to the proximity of other nesting pairs (see below). Predation was the next most frequent cause of nest failure (14%; 20/139 attempts), and 90% (18/20) of depredation events were caused by badgers (Green and Anthony 1989).

Green and Anthony (1989) found a significant difference in nearest-neighbor distances for successful and deserted Burrowing Owl nests. In all cases where inter-nest distance was <110 m, at least one of the two nests was deserted in mid-nesting cycle (both nests abandoned when <60 m apart, n = 3). Only three of 21 (14%) pairs with inter-nest distances >110 m abandoned one or both nests. Many desertions occurred after hatching (Green and Anthony 1989). Apparently, clumped distributions of badger burrows and limited burrow availability in preferred habitat forced pairs close together; inter-pair competition for food presumably intensified as chick demand grew, available prey switched from small rodents to insects, and foraging bouts were conducted increasingly close to the nest (Green and Anthony 1989).

Green and Anthony (1989) also documented that 72% (23/32) of successful nests were lined with cow dung, while only 13% (2/15) of unsuccessful nests were lined. Presumably, dung masks the scent of the birds and thus lining nests with dung appears to be an adaptation to escape detection by predators.

Of five habitat types surveyed for Burrowing Owls, sites dominated by snakeweed, cheatgrass, and antelope bitterbrush were used by owls. Sites dominated by grasses (primarily needlegrass, Sandberg bluegrass, and bluebunch wheatgrass), or rabbitbrush were not used, despite having nearly twice the number of available badger burrows. Over-grazed snakeweed habitat was preferred, where burrows were surrounded with little grass cover conveying greater horizontal visibility than at less grazed sites. The success of Burrowing Owls nesting in the Columbia Basin appears to be dependent on a combination of the availability of properly-spaced badger burrows in preferred habitat, shifting prey resources during the nesting season, and on predation pressure by badgers (Green and Anthony 1989).

In the Malheur Resource Area, BLM personnel conducted Burrowing Owl surveys two to three times per year for 10 years along three to four survey routes. These data have not been analyzed, however the observers believe no major changes have occurred over the past 10 years (A. Bamman, pers. commun.).

Conservation Activities: In 1982, 13 Burrowing Owls were reintroduced by "hacking" at four artificial burrows in the Agate Desert of Jackson County, Oregon. Birds were obtained for reintroduction from nests in the Klamath Valley. The young were fed for about two months before full release. No reintroduced Burrowing Owls were detected in subsequent years (C. Cwiklinski, pers. commun.). Artificial nest burrows are being installed in areas of historic nesting by Burrowing Owls in Jackson County at the Rogue Valley International Airport and on private land with the goal of providing wintering habitat and stimulating summer use as well (C. Cwiklinski, pers. commun.). Twenty artificial burrows were installed in e. Oregon (Umatilla and Morrow counties) in the spring and summer of 1979

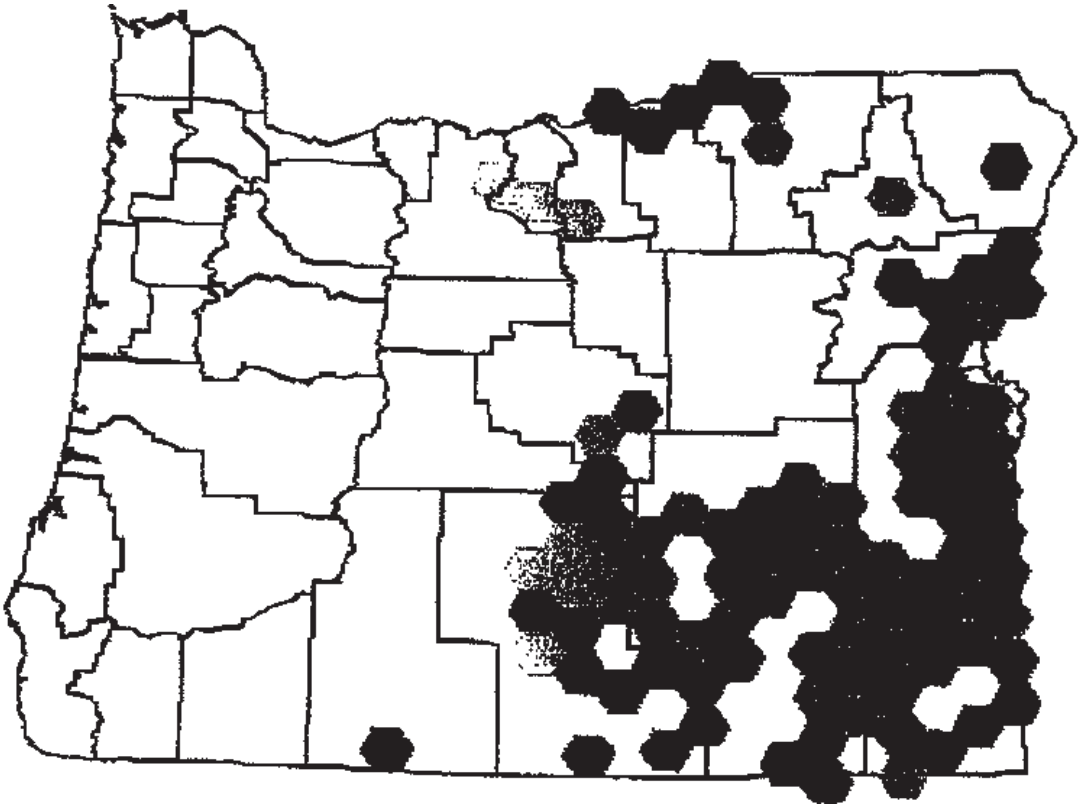

Fig. A-10. Distribution of confirmed (n = 49), probable (n = 9), and possible (n = 37) breeding activity of Burrowing Owls in Oregon from the Oregon Breeding Bird Atlas project (Adamus et al. 2001).

to facilitate research of the species (Henny and Blus 1981). No information was available on the continuation of this project.

In burned shrub-steppe, BLM is now to trying to replant with seed mixes that include sagebrush and other shrubs, and to rehabilitate cheatgrass dominated sites by a combination of prescribed fire, herbicide application and re-seeding with a mix of bunch grasses and shrubs. These efforts to restore the natural vegetation of the area may decrease the quality of habitat preferred by Burrowing Owls. However, BLM is also engaged in land exchanges to consolidate and expand contiguous parcels of Federal land; this probably has a beneficial effect on Burrowing Owls and other wildlife by securing the future ownership of larger blocks of habitat, reducing the chance of future habitat conversion (A. Bamman, pers. commun.).

Major Populations: The Oregon Breeding Bird Atlas (Adamus et al. 2001) shows the bulk of the state's Burrowing Owl population in se. Oregon counties, where they historically occurred (Gabrielson and Jewett 1940); however current and historic densities and numbers of breeding Burrowing Owls are unknown.

State Status: Critical (T&E status pending, or possible if conservation measures are not taken), in the Willamette Valley and Klamath Mountains, High Plains, Columbia Basin, and Blue Mountain physiographic provinces (ODFW 1997).

Natural Heritage Rank: G4/S2?B (imperiled during breeding season because of rarity or other factors making the species very vulnerable to extirpation; (?) indicates uncertainty about rank).

Habitat Use and Condition: Found in sagebrush-steppe, grasslands, pastures, roadsides, and even airports where vegetation is sparse and terrain is level. Also found where soil and/or vegetation has been disturbed through overgrazing, fire, construction, or farming; or at sites where vegetation has been heavily clipped or grazed by ground squirrels (Marshall et al. 1996). Burrows, such as those left by ground squirrels and badgers, are a necessity for breeding.

The areas of high Burrowing Owl populations are lower elevation flat to gently rolling hills with fine grain, deep soils. These areas are at the edge of farmlands where past range fires have repeatedly burned off the sagebrush and heavy grazing

apparently resulted in exotic annual grasses and forbs becoming the dominant plant species. This habitat contains moderate to high rodent numbers and suitable burrows, and is grazed most years. These conditions occur on both private and public lands. Individual Burrowing Owl breeding sites occasionally are found in sagebrush covered areas (A. Bamman, pers. commun.).

Threats: Extirpation of Burrowing Owls through loss of habitat to urbanization and irrigated agriculture has been documented in the Rogue River Valley (Marshall et al. 1996). Habitat conversions of this type are probably more of a threat in n. Oregon than se. Oregon.

Green and Anthony (1989) found predation accounted for 20% of nest failures in n. Oregon (see Research/Monitoring above). Occasional shooting by the public probably has a only a small, local impact.

USDA/APHIS/Wildlife Services poisons ground squirrels and gophers, and traps badgers; these activities could affect burrow availability. USDA/APHIS/Plant Protection and Quarantine conducts grasshopper control operations on a local basis during years when grasshopper populations are exceptionally high. Although direct poisoning is highly unlikely given the pesticides used and methods of application, loss of prey base might affect some pairs of birds some years. The effects of farmer-applied pesticides on birds nesting near and foraging in agricultural fields has not been documented.

Additional threats listed by Altman and Holmes (2000) include: domestic predators (cats and dogs); destruction of burrows through livestock trampling in sandy soils and human disturbance (e.g., ATV use) near nest burrows.

Literature Cited:

Adamus, P. R., K. Larsen, G. Gillson, and C. R. Miller. 2001. Oregon Breeding Bird Atlas. Oregon Field Ornithologists, Eugene, Oregon.

Altman, B. and A. Holmes. 2000. Conservation strategy for landbirds in the Columbia Plateau of eastern Oregon and Washington. Oregon-Washington Partners in Flight. http://community.gorge.net/natres/pif/con_plans/columbia.html

Gabrielson, I. N. and S. G. Jewett. 1940. Birds of the Pacific Northwest. Oregon State College.

Green, G. A., and R. G. Anthony. 1989. Nesting success and habitat relationships of Burrowing Owls in the Columbia Basin, Oregon. Condor 91:347-354.

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: an agency survey. Pages 3-5 in J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Henny, C. J., and L. J. Blus. 1981. Artificial burrows provide new insight into Burrowing Owl nesting biology. Journal of Raptor Research 15:82-85.

Marshall, D. B., M. W. Chilcote, and H. Weeks. 1996. Species at risk: sensitive, threatened and endangered vertebrates of Oregon. 2nd edition. Oregon Department of Fish and Wildlife, Portland, Oregon.

ODFW. 1997. Oregon Department of Fish and Wildlife, Sensitive Species. Web page: http://www.dfw.state.or.us/ODFWhtml/InfoCntrWild/Diversity/senspecies.pdf

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966–2001. Version 2002.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

South Dakota

Summary: Burrowing Owls were previously considered a locally common summer resident in South Dakota west of the Missouri River (except rare in the Black Hills), uncommon to the east, and casual in the winter (South Dakota Ornithologist Union 1991). Based on a survey of biologists, James and Espie (1997) estimated 100 to 1,000 pairs in South Dakota in 1992 with a stable population trend

BBS: A significant negative trend in relative abundance was detected from 1980-2001 (Trend = –11.4, P <0.08, n = 10). No significant trends were noted for other survey periods. Deficiencies in data quality were moderate (sample sizes <14, sub-interval trends significantly different from each other) (Sauer et al. 2002).

CBC: N/A.

Atlas: According to results of the South Dakota Breeding Bird Atlas (Peterson 1995), the Burrowing Owl is now "uncommon and scattered." Concentrations were noted in and near Buffalo Gap National Grassland, Badlands National Park, and the following counties: River Falls, Custer, Pennington, Meade, and Shannon in sw. South Dakota, and McPherson, Edmunds, Faulk, and Hand in nc. South Dakota (Fig. A-11). During field work for the South Dakota Breeding Bird Atlas, Burrowing Owls were found in 12.1% of random bocks with totals of 1 bird observed in each of 10 random blocks and 2-10 birds detected in each of five blocks (Peterson 1995). Of reported Burrowing Owl locations, 87 were from prairie dog towns and 42 from were from upland grassland sites (Peterson 1995).

Research/Monitoring: In 1991, Martell et al. (1993) documented a density of 1 pair/68 ha (0.015 pairs/ha) on prairie dog towns in Badlands National Park (Pennington and Jackson counties) in sw. South Dakota. In 1992, density on the same five towns was 1 pair/41 ha (0.024 pairs/ha) and density on three additional towns was 1 pair/48.5 ha. (0.021 pair/ha). The increase in Burrowing Owls detected from 1991-92 was partially due to increases in the area surveyed (from 819 ha to 1506 ha); however, for towns surveyed both years, increases were noted in the number of pairs (from 14 to 20 pairs), young (29 to 62 young), and average brood size (2.07 young/pair to 3.10 young/pair) indicating actual population increases between years.

Martell et al. (1993) applied the area-occupied technique of relative abundance estimation (Iverson and Fuller 1989) to Burrowing Owls on prairie dog towns in Badlands National Park. They determined the proportion of the area surveyed that was occupied by Burrowing Owls was 0.34 (SE = 0.07) in 1991. In 1992 the proportion of the area occupied increased to 0.57 (SE = 0.07). The probability of detection was 0.486 (SE = 0.056) for all study areas combined.

In the Conata Basin of Buffalo Gap National Grassland (Pennington and Jackson counties), Martell et al. (1993) documented 14 Burrowing Owl broods in 1991 and 11 Burrowing Owl broods in 1992, but did not provide a description of study area boundaries or density estimates. MacCracken et al. (1985) found that Burrowing Owls in the Conata Basin used burrows in early stages of plant succession (high forb and buffalograss cover, and reduced blue grama and perennial plant cover) where vegetation height was lower than the surrounding prairie.

Conservation Activities: Burrowing Owls are monitored as a sensitive species by the South Dakota Natural Heritage Program. Known information about nesting sites is included in environmental review comments on projects submitted for comment to the Heritage Program.

The Crow Creek Sioux Tribe plans to maintain the current number of prairie dogs and prairie dog towns through a Candidate Conservation Agreement with the U.S. Fish & Wildlife Service (L. Fredrickson, pers. commun.).

Major Populations: Concentrations of Burrowing Owl observations were noted in and near Buffalo Gap National Grassland, Badlands National Park, and the following counties: River Falls, Custer, Pennington, Meade, and Shannon in sw. South Dakota, and McPherson, Edmunds, Faulk, and Hand in nc. South Dakota (Peterson 1995).

State Status: None

Natural Heritage Rank: G4/S3S4B, SZN (S3—rare and uncommon breeding populations in the state, S4—widespread, abundant, and apparently secure in state, with many occurrences, but of long-term concern, no non-breeding occurrences).

Habitat Use and Condition: Results from the South Dakota Breeding Bird Atlas supported the importance of prairie dog towns to nesting Burrowing Owls. The majority of black-tailed prairie dogs presently occur on federal or tribal lands, although smaller colonies on private lands are undoubtedly important Burrowing Owl nesting areas as well. Prairie dog numbers and acreage are stable on the Lower Brule Sioux Tribal lands (S. Grassel, pers. commun.).

Threats: Any threats to black-tailed prairie dogs will impact Burrowing Owls in South Dakota. At present, the prairie dog population appears stable, although no systematic surveys are conducted on nesting Burrowing Owls (E. Dowd-Stukel and D. Backlund, pers. commun.). Rapid reductions in Richardson's ground squirrel abundance on private lands are also causing loss of potential Burrowing Owl habitat (R. Peterson, per. commun.)

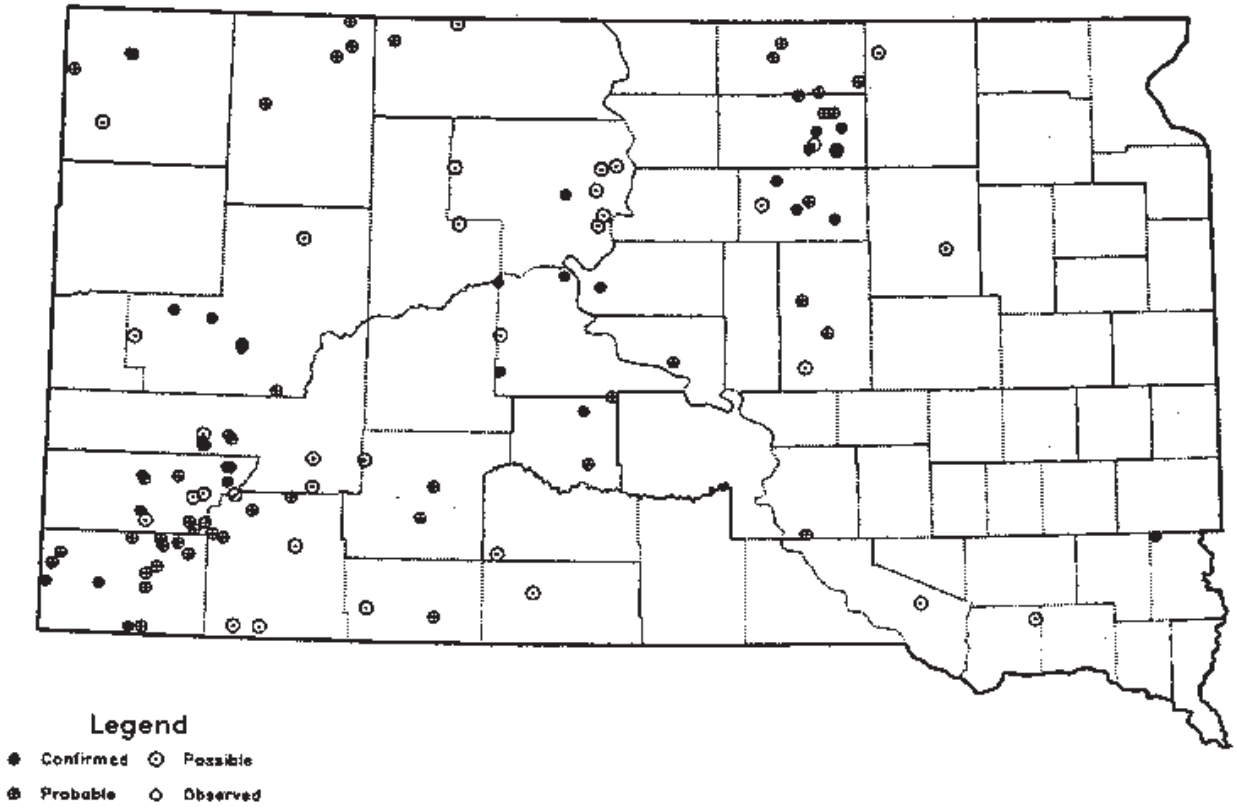

Fig. A-11. Distribution of Burrowing Owl breeding activity and observation in South Dakota from the South Dakota Breeding Bird Atlas project (Peterson 1995).

Literature Cited:

Iverson, G. C. and M. R. Fuller. 1989. Area-occupied survey techniques for nesting woodland raptors. Pages 118-124 *in* Proceedings of the Midwest Raptor Management Symposium and Workshop. National Wildlife Federation, Washington, DC

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: an agency survey. Pages 3-5 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

MacCracken, J. G., D. W. Uresk, and R. M. Hansen. 1985. Vegetation and soils of Burrowing Owl nest sites in Conata Basin, South Dakota. Condor 87:152-154.

Martell, M. S., P. T. Redig, and J. Nibe. 1993. Demography of the Burrowing Owl in Badlands National Park: Final Report. The Raptor Center, Univ. of Minnesota, St. Paul, Minnesota.

Peterson, R. A. 1995. South Dakota Breeding Bird Atlas. South Dakota Ornithologists' Union, Aberdeen, South Dakota.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966-2001. Version 2002.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

South Dakota Ornithologists' Union. 1991. The Birds of South Dakota, Second Edition Aberdeen, South Dakota.

Texas

Summary: Burrowing Owls are an uncommon to common resident on the open prairies of the western half of the state, east to Wilbarger County. It is a rare migrant and winter visitor east to coastal Texas (Texas Ornithological Society 1995). In winter, Burrowing Owls are locally fairly common to uncommon in the c. and s. Panhandle, but usually withdraw from the n. Panhandle. Based on a survey of biologists in 1992, James and Espie (1997) estimated more than 10,000 pairs in Texas.

BBS: No significant trends were detected over any survey period (Sauer et al. 2002).

CBC: No significant trend detected over the survey period (1959-88) (Sauer et al. 1996).

Atlas: Unknown.

Research/Monitoring: In s. Texas (primarily the Corpus Christi area) a monitoring effort sponsored by the Canadian Wildlife Service, U.S. Geological Survey-Texas Gulf Coast Field Research Station, and the Texas A&M University-Corpus Christi was begun in the winter of 1998-99 and continues to the present. This cooperative project currently is focused on documenting range, numbers, and habitat use throughout agricultural areas of s. Texas and to determine the response to installation of artificial burrows. Plans are underway to trap, band, and place radio transmitters on Burrowing Owls to monitor over-winter movements and survival. Ongoing collection of pellets and feathers in Texas will continue for diet and isotope studies. (C. Shackelford, pers. commun.).

Conservation Activities: None documented.

Conservation Recommendations: None documented.

Major Populations: Mackenzie State Park in Lubbock. This population is currently threatened by the city of Lubbock's plan to eradicate prairie dogs from the area. No other major populations documented.

State Status: None

Natural Heritage Rank: G4/S3B (rare and uncommon breeding populations in the state).

Habitat Use and Condition: Habitat includes culverts along roads adjacent to plowed fields or cleared pastures. Areas immediately around occupied culverts have short and/or sparse vegetation. Most of these habitats occur on private lands. County roads allow visual sightings of many of the birds; however, numbers of Burrowing Owls wintering on large private ranches are unknown (C. Shackelford, pers. commun.).

Threats: Loss of traditional grassland habitats and associated natural burrows to agriculture and development are a primary threat. Vehicle collisions due to use of roadside culverts for burrows and ingestion of pesticides from prey associated with agricultural fields are also threats (C. Shackelford, pers. commun.).

Literature Cited:

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: an agency survey. Pages 3-5 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966-2001. Version 98.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

Sauer, J. R., S. Schwartz, and B. Hoover. 1996. The Christmas Bird Count Home Page. Version 95.1 U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr.nbs.gov/bbs/cbc.html.

Texas Ornithological Society. 1995. Checklist of the birds of Texas 3rd edition. Capital Printing, Inc. Austin, Texas.

Utah

Summary: The Burrowing Owl is an uncommon permanent resident with localized occurrence (Behle and Perry 1975). Populations appear to have declined across the range; its distribution has been localized in many areas of Utah (Utah Division of Wildlife Resources 1998). Based on a survey of state biologists, James and Espie (1997) estimated 1,000 to 10,000 pairs in Utah in 1992 with a decreasing population trend.

BBS: No significant trends were detected for any survey period (Sauer et al. 2002).

CBC: The Burrowing Owl is a casual wintering resident in s. Utah.

Atlas: Unknown.

Research/Monitoring: Little published research was identified for Utah.

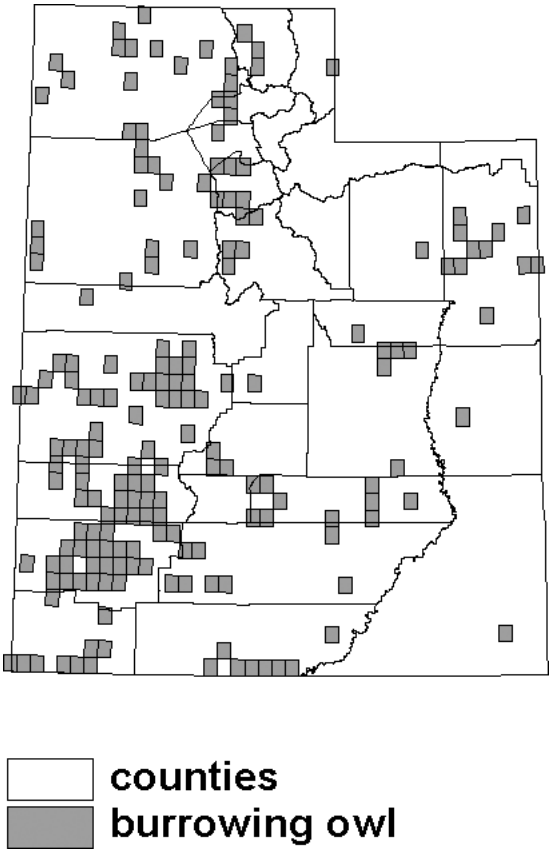

Fig. A-12. Distribution of Burrowing Owl observations in Utah (Utah Natural Heritage Program, A. Axel, pers. commun.).

Conservation Activities: None identified.

Major Populations: None identified.

State Status: Species of Special Concern.

Natural Heritage Rank: G4/S3B (rare and uncommon breeding populations in the state).

Habitat Use and Condition: Not documented.

Threats: None documented

Literature Cited:

Behle, W. H., and M. L. Perry. 1975. Utah birds: check-list, seasonal and ecological occurrence charts and guides to bird finding. Utah Museum of Natural History, Univ. of Utah, Salt Lake City, Utah.

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: an agency survey. Pages 3-5 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966-2001. Version 2002.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

Utah Division of Wildlife Resources. 1998. Utah Sensitive Species List. Utah Division of Wildlife Resources homepage (http://www.nr.state.ut.us/dwr/sensppl.htm#bird). October, 2000.

Washington

Summary: Burrowing Owls are local and uncommon in shrub-steppe and grassland habitats east of the Cascades. It is widespread in the southern part of this region, but numbers fluctuate and breeders are limited to areas with suitable burrow sites. West of the Cascades, the Burrowing Owl was historically a rare migrant and winter resident of the n. Puget Sound region. It perhaps once nested in the vicinity of Bellingham, south of Tacoma, and Grays Harbor (Jewett et al. 1953). Smith et al. (1997) stated that in most areas numbers are seriously declining, and that losses are especially pronounced in the channeled scablands, Okanogan Valley, and se. Washington. This statement is supported by nest site occupancy analyses by Washington Department of Fish and Wildlife (WDFW), Wildlife Resources Data System (unpubl. data).

BBS: No significant trends were detected over any survey period (Sauer et al. 2002).

CBC: N/A.

Atlas: No breeding bird atlas is available for Washington; information regarding distribution is from the Washington Wildlife Resources Data System (Fig. A-13). Confirmed breeding records are concentrated in sc. Washington (east of the Cascades), in sw. Adams, extreme w. Walla Walla, Franklin, Grant, Benton, e. Yakima, and s. and e. Klickitat counties. Also in w. Whitman, c. Lincoln, sw. and n. Douglas, and s. Okanogan counties. There are no recent breeding records or suitable habitat west of the Cascades (Smith et al. 1997).

Research/Monitoring: WDFW surveys in 1987, 1999, and 2000 and occasional incidental observations of nest locations since 1960 show that the most significant change in distribution from pre-1987 to post-1987 is the apparent loss of owls from c. Okanogan County along the Okanogan River plain. GAP analysis also shows no remaining potential habitat for owls in this region (Smith et al. 1987). Other range changes are not as striking but involve the loss of burrow sites in se. Yakima County and s. Lincoln County (WDFW, Wildlife Resources Data System, unpubl. data).

The 1987 WDFW study was originally conducted to assess the status of the Washington State population, and its ability to absorb losses from a transplant program designed to re-establish Burrowing Owls in British Columbia. Additional nest information was collected, however, and follows (Radke 1987). The study was concentrated in a relatively small area of Grant (south of Ephrata), w. Adams, and nw. Franklin counties. Of the 117 nests found, 39% (46/117) were on county roadside rights-of-way (≤ 10 feet to the road). These data may be biased as they were predominantly conducted while driving roads. Only 13% (15/117) of the nests were in areas considered 'natural'. The remaining 45% (52/117) were roughly equally divided between pasture, canal and ditch banks, and vacant lots. Of all nests, 74% were within 50 feet of roads. By far the greatest disturbance to nests was vehicles or recreational uses (100 nests), followed by disturbance from agricultural operations (from cattle operations, 17 nests; grain crop activities, 10 nests; truck crop activities, 9 nests). Disturbance from development, industrial, and residential activities affected 16 nests altogether. Natural burrows accounted for 72% (84/117) of the nests; the rest were in culverts or irrigation pipes (21%, 25/117) or in artificial nest burrows (7%, 8/117).

In 1999 and 2000 WDFW surveyed approximately 80% of all previously documented Burrowing Owl nesting sites in Washington. All nest sites visited were classified as either occupied, unoccupied, destroyed, or not found (Table A-4, WDFW, Wildlife Resources Data System, unpubl. data).

Conservation Activities: Prairies and steppe, and shrub-steppe habitats are listed as "Priority Habitats" by WDFW under the Priority Habitat and Species (PHS) Program. This designation facilitates consideration of conservation needs and measures during state and local land use planning. WDFW is currently developing management guidelines to promote the conservation of all priority habitats and species identified under the PHS Program. This will include conservation guidelines for prairies and steppe, and shrub-steppe habitats and species management guidelines for the conservation of Burrowing Owls. WDFW also plan to conduct a state status assessment for Burrowing Owls and searches for Burrowing Owls will be intensified in se. Washington (E. Cummings, pers. commun.).

Radke (1987) and Smith et al. (1997) mentioned that artificial nest burrows have been placed by conservation groups. No concerted or systematic nest box programs are known, however.

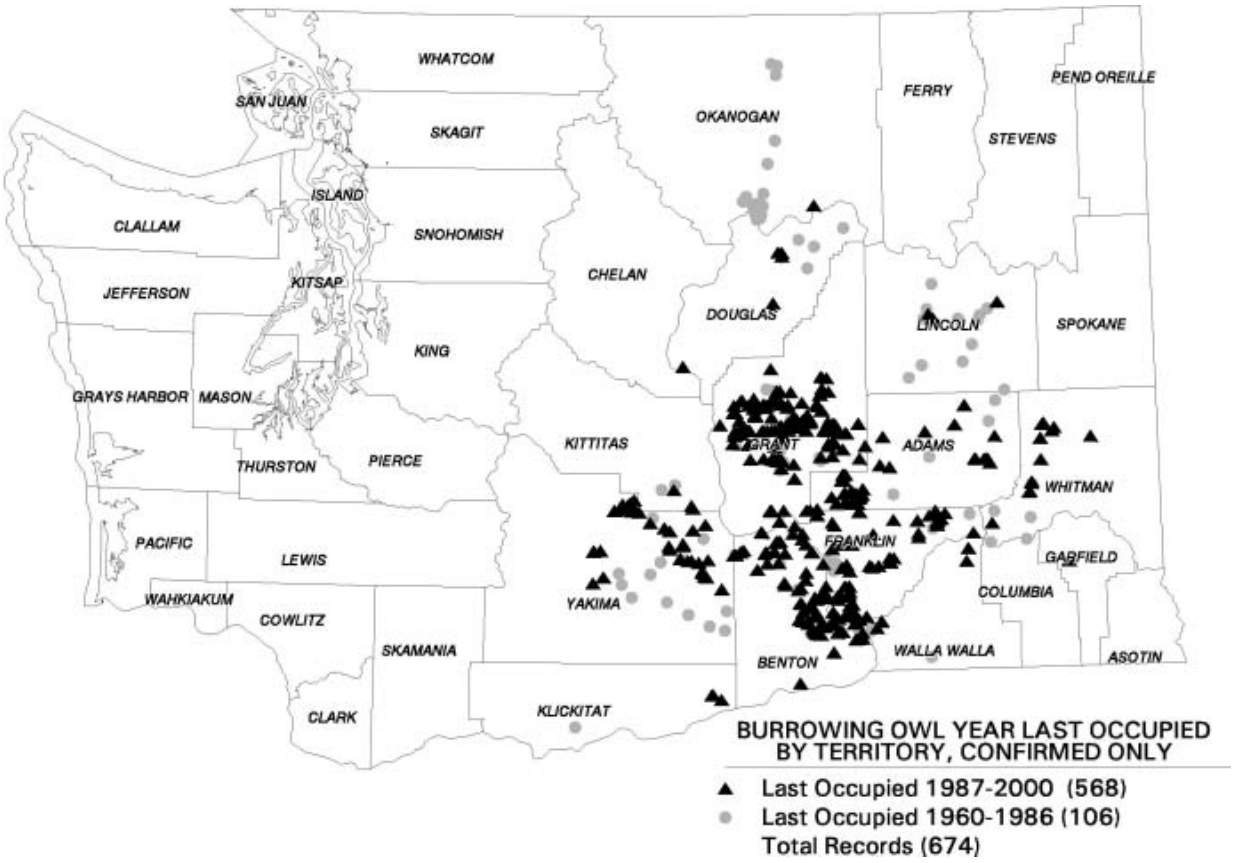

Fig. A-13. Distribution of Burrowing Owls burrows in Washington (Washington Department of Fish and Wildlife, Wildlife Resources Data System, J. Brookshier, pers. commun.).

Table A-4. Number of occupied, unoccupied, destroyed, and not found Burrowing Owl nests located in Washington during Washington Department of Fish and Wildlife surveys in 1999 and 2000.

Year	Occupied	Unoccupied	Destroyed	Not Found	Total # Sites Visited
1999	170	100	44	141	455
2000	195	220	54	130	599

Major Populations: Grant and Franklin counties hold over half (55%) of nest sites in the State, occupied or historical (WDFW, Wildlife Resources Data System, unpubl. data 2001).

State Status: Candidate for listing as State Endangered, Threatened, or Sensitive.

Natural Heritage Rank: G4/S3B (rare and uncommon breeding populations in the state)

Habitat Use and Condition: Most nest sites located by Radke (1987) were near agricultural areas, and 21% were in artificial burrows of some sort, such as culverts and irrigation pipes. About 75% of nests found were within 50 feet of roads. Thus, disturbed, artificial situations are often used by these birds in Washington.

Threats: Loss of historic nest sites to agricultural conversion has been documented in Walla Walla County (Smith et al. 1997). However, agriculture has provided habitat in some areas (E. Cummings, pers. commun.).

The Burrowing Owl is currently a candidate for listing as Threatened, Endangered, or Sensitive in Washington. This designation serves to facilitate consultation with WDFW regarding state and local land use planning but no specific regulatory protection is afforded beyond that of other native wildlife species in Washington

Literature Cited:

Jewett,S. G., W. P. Taylor, W. T. Shaw, and J. W. Aldrich. 1953. Birds of Washington State. Univ. of Washington Press, Seattle, Washington.

Radke, M. 1987. Burrowing Owls in the Columbia Basin, Washington, 1987. British Columbia Conservation Foundation Report. June 28, 1987.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966-2001. Version 2002.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html.

Smith, M. R., P. W. Mattocks, Jr., and K. M. Cassidy. 1997. Breeding birds of Washington State. Volume 4 *in:* K.M. Cassidy, C.E. Grue, M.R. Smith, and K.M. Dvornich, editors. Washington State Gap Analysis—Final Report. Seattle Audubon Society Publications in Zoology No. 1, Seattle, Washington.

Wyoming

Summary: Burrowing Owls occur statewide in grasslands and open areas of shrub-steppe regions. Burrowing Owls have been documented in all latilong blocks in the state but are considered uncommon (Wyoming Game and Fish Dept. 1997). Marti and Marks (1989) listed Burrowing Owls as common in Wyoming with an unknown population trend. They listed more than 200 nesting pairs and more than 200 nest sites from 1977-86, based on a National Wildlife Federation survey of state wildlife agencies in 1987. Based on a survey of state biologists, James and Espie (1997) estimated 1,000 to 10,000 pairs in Wyoming in 1992 with a stable population trend.

BBS: Significant negative declines were detected 1966-2001 (Trend = –23.7, P <0.04, n = 11). No significant trends were detected for other survey periods. Deficiencies in data quality were moderate (sample sizes <14, sub-interval trends significantly different from each other) (Sauer et al. 2002).

CBC: N/A

Atlas: No breeding bird atlas is available for Wyoming. Burrowing Owls were recorded as breeding in 24 of 28 latilongs and observed in all latilongs (Wyoming Game and Fish Dept. 1997). The Wyoming Natural Diversity Database (WYNDD) maintains a database of historic and current Burrowing Owl observations throughout Wyoming. Records are from various sources such as the Wyoming Game and Fish Dept. Wildlife Observation System (WOS), agency surveys, university research projects, and personal observations; all of which are scrutinized for credibility (D. Keinath pers. commun.).

Research/Monitoring: Martin (1983) recorded Burrowing Owl observations while conducting day and night searches for black-footed ferrets in sc. and sw. Wyoming from June through September of 1978-82. He found 86 Burrowing Owls on 34 of 426 (8.0%) white-tailed prairie dog colonies. This included 14,349 ha searched on 16 colonies in Sweetwater, 14 in Carbon, three in Uinta, and one in Lincoln counties. Nest burrows with young were documented on 10 (2.4%) colonies (2.7 ± 0.5 young / nest, range 1-5). Burrowing Owl density on white-tailed prairie dog colonies was one adult/172.5 ha. Low Burrowing Owl density was attributed to taller vegetation and less open habitat on white-tailed versus black-tailed prairie dog colonies (Martin 1983). Colonies occupied by Burrowing Owls averaged 72.8 ± 13.2 ha (n = 33; range 0.8-325.1) with 31.6 ± 6.9 burrows / ha (n = 25; range 4.7-167.2). Colonies with owl nests averaged 74.0 ± 12.8 ha (n = 10; range 27.5-147.8) with 20.0 ± 2.7 burrows / ha (n = 9; range 7.2-34.3; Martin 1983).

The WYNDD (June 2000) has documented 43 Burrowing Owl occurrences in the state. An "occurrence" is a locality where multiple Burrowing Owls or confirmed breeding/nesting behavior have been documented. An occurrence generally represents an established prairie dog town that reliably contains several nesting pairs of owls each year (Keinath pers. commun.).

In 1999 and 2000, the Rocky Mountain Bird Observatory (RMBO) conducted roadside surveys of potential Burrowing Owl habitat in se. Wyoming including most of Platte, Goshen, and Laramie counties, and extreme s. Niobrara County. In 1999, RMBO located 71 colonies of Burrowing Owls, totaling 180 individuals (Hutchings et al. 1999). In 2000, they located 107 sites with 575 Burrowing Owls; site reoccupancy was 66% between 1999 and 2000 (T. VerCauteren pers. commun.).

In 1998, the U.S. Forest Service conducted surveys for Burrowing Owls on black-tailed prairie dog towns within the Great Plains National Grasslands (Sidle et al. 2001). In the n. Great Plains (including Wyoming), 196 (59%) of 330 active towns were occupied by Burrowing Owls, and 12 (25%) of 48 inactive towns had owls. However, only 16% of prairie dog towns on Thunder Basin National Grassland in northeastern Wyoming had owls. Furthermore, Sidle et al. (2001) noted that surveys in 1995 failed to locate Burrowing Owls on Thunder Basin, but did not provide information on the extent or conditions of surveys.

Korfanta et al. (2001) examined Burrowing Owl sightings in the WOS. Burrowing Owl sightings were broadly distributed throughout Wyoming, with the highest concentrations occurring in the southern half of the state (Fig. A-14). Two trends were evident from the WOS data (Figure A-15): numbers of records generally increased between 1974-80, while record numbers decreased between 1981-97. There was a significant, negative linear relationship ($P = 0.002$, $r^2 = 0.64$) between numbers of Burrowing Owl sightings and time for the 1986-97 subset of the WOS data (Fig. A-15). However, there may be potential reporting bias in the WOS, which might obscure real population trends.

Korfanta et al. (2001) surveyed 103 historic sites and 85 random sites selected on the basis of vegetation in eastern Wyoming in 1999. A total of 37 Burrowing Owls were seen at 16 sites; 36 on WOS historical sites (n = 103), one on a "high probability" site (n = 55), and none on "low probability" sites (n = 30). High probability sites were comprised of northern mixed- or short-grass prairie while low probability sites contained sub-optimal Burrowing Owl habitat such as sagebrush or open ground. A total of 43% of occupied sites (n = 16) and 10% of unoccupied sites (n = 168) were also occupied by black- or white-tailed prairie dogs. Twenty-percent of the occupied sites were currently or recently (within the previous year) grazed by cattle, sheep, or buffalo.

Conservation Activities: Burrowing Owls are monitored and managed within the vicinity of surface mines as mandated by the federal Surface

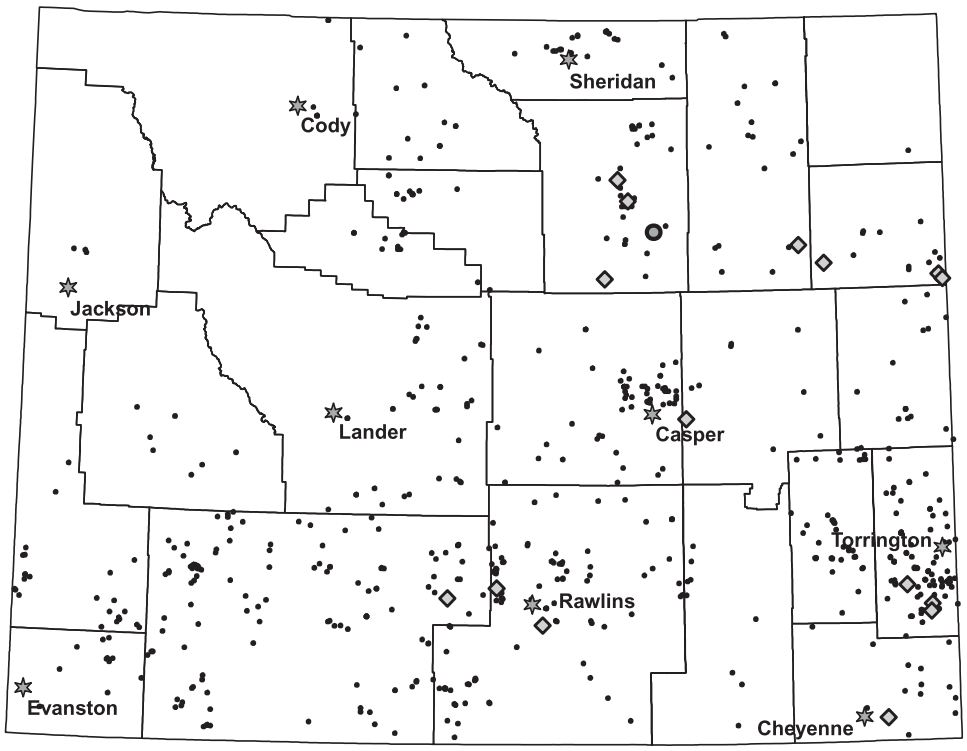

Fig. A-14. Historic Burrowing Owl records (dots) from the Wyoming Game and Fish Department Wildlife Observation System and reoccupancy survey sites with Burrowing Owls (diamonds) in 1999 (from Korfanta et al. 2001).

Fig. A-15. Numbers of Burrowing Owl records per year in the Wyoming Game and Fish Department Wildlife Observation System. The trend line for the 1986 – 1997 period represents a period of presumed consistent search effort (from Korfanta et al. 2001).

Mining Control and Reclamation Act of 1977 (30 U.S.C. 1201).

Major Populations: Burrowing Owl sightings are distributed primarily in e. and s. Wyoming with higher concentrations around Torrington, Sheridan, and Rawlins (Fig. A-14) although this may reflect a reporting bias in WOS data whereby owls are more readily detected near population centers (Korfanta et al. 2001). Hutchings et al. (1999) found 107 sites with Burrowing Owls in Platte, Goshen, Laramie, and s. Niobrara counties in 2000. Significant potential habitat exists on Thunder Basin National Grassland; however, few Burrowing Owls were documented during 1995 and 1998 surveys of prairie dog towns within the Grassland (Sidle et al. 2001).

State Status: Species of Special Concern (Category 4)

Natural Heritage Rank: G4/S3B, SZN (rare and uncommon breeding populations in the state, no non-breeding occurrences)

Habitat Use and Condition: During re-occupancy surveys of historic nest sites in e. Wyoming, Korfanta et al. (2001) found 43% of Burrowing Owls observed in 1999 were associated with prairie dog colonies. Only one Burrowing Owl was located during surveys of 85 random sites in the same region, which included 55 high probability sites in northern mixed- or short-grass prairie and 30 low probability sites with sagebrush, irrigated croplands, or desert shrub as the dominant cover type.

Only 1.9% of the Great Plains National Grasslands deemed suitable for prairie dogs was inhabited by the species (Sidle et al. 2001). The U.S. Forest Service estimated Thunder Basin National Grassland contains 1,013 ha of active prairie dog towns at approximately 121 burrows/ha. National Grasslands in general are fragmented, making active prairie dog management difficult, and there is no concerted effort to restore prairie dog towns. Despite this, Great Plains National Grasslands offer abundant potential habitat for prairie dogs and therefore, Burrowing Owls (Sidle et al. 2001).

Threats: Destruction of prairie dog habitat and rodent control are believed to have reduced Burrowing Owl numbers in the state (Wyoming Game and Fish 1977, Martin 1983, Sidle et al. 2001). Sylvatic plague outbreaks in prairie-dog populations have also reduced available Burrowing Owl habitat in Wyoming (USFWS 2000). Recreational shooting of prairie dogs may also significantly influence population size and therefore, available Burrowing Owl habitat in portions of Wyoming.

Literature Cited:

Hutchings, S., M. Carter, E. Atkinson, T. VerCauteren, C. Finley, S. Gillihan, and J. Nocedal. 1999. Prairie Partners: Promoting stewardship of shortgrass prairie. Unpubl. Rep., Colorado Bird Observatory, Brighton, Colorado.

Korfanta, N. M., L. W. Ayers, S. H. Anderson, and D. B. McDonald. 2001. A preliminary assessment of Burrowing Owl population status in Wyoming. Journal of Raptor Research 35:337-343.

James, P. C., and R. H. M. Espie. 1997. Current status of the Burrowing Owl in North America: An agency survey. Pages 3-5 *in* J. Lincer and K. Steenhof, editors. The Burrowing Owl, its biology and management including the Proceedings of the First International Burrowing Owl Symposium. Raptor Research Report Number 9.

Marti, C. D., and J. S. Marks. 1989. Medium-sized owls. Pp. 124-133 *In:* B. A. Giron Pendleton, editor. Proceedings of the Western Raptor Management Symposium and Workshop, National Wildlife Federation, Washington, DC

Martin, S. J. 1983. Burrowing Owl occurrence on white-tailed prairie dog colonies. Journal of Field Ornithology 54:422-423.

Sauer, J. R., J. E. Hines, and J. Fallon. 2002. The North American Breeding Bird Survey, Results and Analysis 1966-2001. Version 2002.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland. http://www.mbr-pwrc.usgs.gov/bbs/bbs2001.html

Sidle, J. G., M. Ball, D. Weber, J. Chynoweth, G. Foli, R. Hodorff, G. Moravek, and R. Peterson, D. Svingen. 2001. Occurrence of Burrowing Owls in prairie dog towns on Great Plains. Journal of Raptor Research 35:316-321.

U.S. Fish and Wildlife Service. 2000. Endangered and threatened wildlife and plants: 12-month finding for a petition to list the black-tailed prairie dog as Threatened. Proposed Rules. Federal Register 65:5476-5488 (Feb. 4, 2000).

Wyoming Game and Fish Dept. 1997. Atlas of Birds, Mammals, Reptiles, and Amphibians in Wyoming. Wyoming Game and Fish Dept., Wildlife Division, Biological Services Section, Lander, Wyoming.

Arkansas, Illinois, Missouri, Wisconsin

Summary: IL, MO, WI: Vagrant; AR: Irregular migrant and winter resident

BBS: N/A

CBC: N/A

Atlas: N/A

Research/Monitoring: No research identified.

Conservation Activities: No conservation activities reported.

Major Populations: None.

State Status:

AR: State—None. There are a few scattered, records in the 1960's in Lonoke County. Single birds have been reported in Arkansas, Craighead, Cross, Crittenden, Jefferson, Mississippi, Pope, and Prairie counties (James and Neal 1986)

IL: Status—Nongame Protected. The Burrowing Owl is a very rare spring vagrant in n. and c. Illinois (Illinois Natural Resources Information Network 2000). No breeding records exist.

MO: Status—None. The Burrowing Owl is transient in w. Missouri and accidental in eastern Missouri during migration. It is an accidental summer and winter resident with one confirmed breeding record.

WI: State—None. The Burrowing Owl is a vagrant in Wisconsin. Undocumented historic observations suggest potential isolated breeding. There were 12 accepted state records between 1939 and 1992 (R. Domagalski, pers. commun.).

Natural Heritage Rank: AR: Unknown; IL: SA (Accidental in State); MO, WI: S? (Unranked in State).

Habitat Use and Condition: Unknown

Threats: Unknown

Literature Cited:

Illinois Natural History Information Network. 2000. Illinois Birds: Burrowing Owl (*Athene cunicularia*). Illinois Natural History Survey webpage (http://www.inhs.uiuc.edu/chf/pub/ifwis/birds/index.html) version August, 2000.

James, D. A., and J. C. Neal. 1986. Arkansas Birds: Their distribution and Abundance. University of Arkansas Press, Fayetteville, Arkansas.

Appendix B: Summary of Conservation Recommendations for Burrowing Owls

Below is a summary of conservation recommendations from western states gleaned from the literature, State wildlife agencies, Partners in Flight Bird Conservation Plans, and researchers in the field. Sources of the summarized conservation recommendations for each state are listed at the end of this section. Discussion of on-going conservation activities in each state can be found in Appendix A. There is considerable variability in the recommendations, but they are generally organized into six categories (Table B-1). No recommendations were found for Arizona, New Mexico, Oklahoma, Texas, or Utah.

Statewide Management Strategies

A statewide management strategy was suggested for Burrowing Owls in California, addressing ground squirrel control policies, fire management and agricultural practices, and land management on golf courses, airports, and private lands. Additionally, it was recommended the State relocate Burrowing Owls threatened by development, while striving to maintain populations encircled by development.

Recommendations in Nevada included development of Best Management Practices for rangeland pesticides and minimizing use, particularly in areas of high Burrowing Owl density. The impacts of off-road vehicles could be mitigated by adjustment of sanctioned event routes and closure of casual use in Burrowing Owl breeding centers, presumably regulated by State and Federal agencies.

Artificial Burrows

Artificial Burrows as a means of maintaining current populations or encouraging populations to immigrate to new sites was recommended in California, Idaho, and Nevada. Care was suggested in Nevada to place artificial burrows, whether used as mitigation or not, in protected areas suitable to support owls. The suggestion of a "Burrowing Owl trail," as with bluebirds, was made in Minnesota.

Relocation

Relocation of colonies away from impending development was suggested in California, where development pressure in several areas of the state is especially great, although most relocations were unsuccessful.

Surveys and Research

Surveys were recommended in California, Minnesota, Nebraska, Nevada (Mojave Desert region), North Dakota, and South Dakota, either to locate new nest sites, monitor known sites, or both. Survey recommendations in North Dakota included the development of a database of incidental sightings in the State. Research recommendations in North Dakota included detailed studies of Burrowing Owl reproductive success and survival (particularly on prairie dog colonies). In Nevada, research on the impacts of rangeland pesticides and off-road vehicles on Burrowing Owls, and on the degree to which populations are reliant on agriculture was recommended.

Education

Education of people who shoot ground squirrels and prairie dogs was recommended in Colorado, Minnesota, and Montana. Farmers and off-road vehicle enthusiasts are suggested targets of education in Nevada. In Nevada, it was suggested that USDA Natural Resource Conservation Service (NRCS) extension services could help to educate the farming community regarding the benefits of field margins as wildlife habitat, the effects of the indiscriminate use of insecticides and rodenticides, and the advantages of maintaining high raptor populations to control pests on crop and pasture lands.

Table B-1: General categories of conservation recommendations for Burrowing Owls from states for which recommendations were found[1].

	CA	ID	MN	MT	NE	NV	ND	OR	SD	WA	WY
Statewide Management Strategy	◆					◆					
Artificial Burrows	◆	◆	◆			◆					
Relocate Owls	◆										
Surveys & Research	◆		◆		◆	◆	◆		◆		
Education			◆	◆		◆					
Habitat Protection & Management, & Burrowing Animal Management		◆	◆	◆	◆	◆	◆	◆	◆	◆	◆

[1]–No recommendations were found for Arizona, Colorado, New Mexico, Oklahoma, Texas, or Utah.

Habitat Protection

Habitat protection and management, and protection and management of burrowing mammals was suggested in several states. Recommendations included the following: introduce fire in shrub-steppe to increase grassland near cropland, reduce the conversion of grasslands and pasture to cultivation, and maintain pesticide- and herbicide-free zones of 600-m radius around burrows (Idaho); leave drain ditches unburned and ditch banks and turnrows undisturbed (Nevada); protect burrow sites (Colorado, Idaho, and Nevada); establish conservation easements with private landowners to secure good owl habitats (Nevada); maintain open ground cover >40%, and native grass cover <40% and <40 cm tall on average, and maintain a 200-m buffer around nest burrows where human activities are prohibited (Oregon and Washington); maintain 100-300 m buffers around nest burrows (Colorado); preserve shortgrass habitat and manage for ground squirrels and badgers (Minnesota); preserve salt desert scrub habitat and its burrowing mammal community (Nevada); manage plague in prairie dog towns and change regulations regarding shooting of prairie dogs and ground squirrels (Montana); survey prairie dog colonies for burrowing owls and reevaluate hunting of prairie dogs (Nebraska and South Dakota); manage habitats for prairie dogs (North Dakota) and restore former prairie dog colonies on National Grasslands (Wyoming); preserve habitat for burrow providers (Oregon and Washington); and work with developers in urban and suburban areas to preserve open space within developments for Burrowing Owls (Nevada).

Sources of Conservation Recommendations

California

California Burrowing Owl Consortium
http://www2.ucsc.edu/scpbrg/owls.htm

J. Barclay, pers. commun.

Colorado

Coloardo Partners in Flight Bird Conservation Plan. 2000. http://rmb.wantjava.com/bcp/index.htm

Idaho

Belthoff, J. R., and R. A. King. 1997. Between-Year Movements and Nest Burrow Use by Burrowing Owls in Southwestern Idaho. Technical Bulletin No. 97-3, Idaho Bureau of Land Management.

Leptich, D. J. 1994. Agriculture development and its influence on raptors in southern Idaho. Nothwest Science 68:167-171.

Rich, T. 1984. Monitoring Burrowing Owl populations: implications of burrow re-use. Wildlife Society Bulletin 12:178-180.

Rich, T. 1986. Habitat and nest-site selection by Burrowing Owls in the sagebrush steppe of Idaho. Journal of Wildlife Management 50:548-555.

Minnesota

Coffin, B. and L. Pfannmuller. 1988. Minnesota's Endangered Flora & Fauna. University of Minnesota Press.

Martell, M. S., J. Schladweiler, and F. Cuthbert. 2001. Status and attempted reintroduction of Burrowing Owls in Minnesota. Journal of Raptor Research 35:331-336.

Montana
Knowles, C. J. *In review*. A Review of Burrowing Owl Observations Recorded in Montana 1964-1999. FaunaWest Wildlife Consultants Rept., Boulder, Montana.

Restani, M., L. R. Rau, and D. L. Flath. 2001. Nesting ecology Of Burrowing Owls occupying prairie dog towns in southeastern Montana. Journal of Raptor Research 35:296-303.

Nebraska
Desmond, M. J., and J. A. Savidge. 1999. Satellite burrow use by Burrowing Owl chicks and its influence on nest fate. Pages 128-130 *in* P. D. Vickery and J. R. Herkert, editors. Ecology and conservation of grassland birds of the western hemisphere. Studies in Avian Biology 19.

Nevada
Neel, L. 1999. Nevada Partners in Flight Bird Conservation Plan. Nevada Partners in Flight. http://www.blm.gov/wildlife/plan/pl-nv-10.pdf

North Dakota
R. Murphy, pers. commun.

Oregon
Altman, B., and A. Holmes. 2000. Conservation strategy for landbirds in the Columbia Plateau of eastern Oregon and Washington, version 1.0. Oregon-Washington Partners in Flight.

South Dakota
E. Dowd Stukel and D. Backlund, pers. commun.

Washington
Altman, B., and A. Holmes. 2000. Conservation strategy for landbirds in the Columbia Plateau of eastern Oregon and Washington, version 1.0. Oregon-Washington Partners in Flight.

Wyoming
Korfanta, N. M., L. W. Ayers, S. H. Anderson, and D. B. McDonald. 2001. A preliminary assessment of Burrowing Owl population status in Wyoming. Journal of Raptor Research 35:337-343.

Sidle, J. G., M. Ball, T. Byer, J. J. Chynoweth, G. Foli, R. Hodorff, G. Moravek, R. Peterson, and D. Svingen. 2001. Occurrence of Burrowing Owls in black-tailed prairie dog colonies of Great Plains National Grasslands. Journal of Raptor Research 35:316-321.

Appendix C: Distribution List for the Burrowing Owl Status Assessment and Conservation Plan

Allen, Harriet
Wildlife Management Program
Washington Dept. of Fish and Wildlife
600 Capitol Way N.
Olympia, WA 98501-1901
Ph: (360) 902-2200

Alvaro, Jaramillo
San Francisco Bay Bird Observatory
1290 Hope Street, P.O. Box 247
Alviso, CA 95002-0247
Ph: (408) 946-6548

Anderson, David
Fisheries and Wildlife Department
University of Minnesota
200 Hodson Hall
St. Paul, MN 55108
Ph: (612) 626-1222
E-mail: dea@fw.umn.edu

Anderson, Stanley
Wyoming Cooperative Fish and Wildlife Research
University of Wyoming
Box 3166, University Station
Laramie, WY 82071

Arrowwood, Patricia
Department of Fish & Wildlife Sciences
NMSU, P.O. Box 30003, Campus Box 4901
Las Cruces, NM 88003-0003
Ph: (505) 526-9427
E-mail: Parrowoo@nmsu.edu

Atkinson, Eric
Marmot's Edge Conservation
4580 E. Baseline Road
Belgrade, MT 59714
Ph: (406) 586-1585
E-mail: sawwhet@mcn.net

Axel, Anne, Information Manager
Utah Natural Heritage Program
Division of Wildlife Resources
1594 West North Temple
Salt Lake City, UT 84114-6301
Ph: (801) 538-4759
E-mail: anneaxel@utah.gov

Bammann, Albert, Wildlife Biologist
Bureau of Land Management
100 Oregon Street
Vale, OR 97918
Ph: (541) 473-6283
E-mail: al-bammann@or.blm.gov

Banasch, Ursula
1223 85th Street
Edmonton, AB T6K 1X7
Canada
Ph: (780) 951-8678
E-mail: ursula.banasch@ec.gc.ca

Barclay, Jack
Albion Environmental, Inc.
1414 Soquel Avenue, No. 205
Santa Cruz, CA 95062
Ph: (831) 426-6847
E-mail: jbarclay@albionenvironmental.com

Beauvais, Gary, Heritage Zoologist
Wyoming Natural Diversity Database
1604 Grand Avenue, Suite 2
Laramie, WY 82070-4332
Ph: (307) 766-3023
E-mail: beauvais@uwyo.edu

Belthoff, Jim
Department of Biology
Boise State University
Boise, ID 83725-1515
Ph: (208) 426-4033
E-mail: Jbeltho@boisestate.edu

Benz, Carl, Assistant Field Supervisor
U.S. Fish and Wildlife Service, South Coast/Desert
2493 Portola Road, Suite B
Ventura, CA 93003
Ph: (805) 644-1766
E-mail: Carl_Benz@r1.fws.gov

Bildstein, Keith
Hawk Mountain Sanctuary
1700 Hawk Mountain Road
Kempton, PA 19529-9449
Ph: (610) 756-6961
E-mail: bildstein@say.acnatsci.org

Bird, David
Avian Science & Conservation Center
McGill University
21111 Lakeshore Road
Ste. Anne De Bellevue, QC H9X 3V9
Canada
Ph: (514) 398-7760
E-mail: bird@nrs.mcgill.ca

Botelho, Eugene
58 Ohio Street
New Bedford, MA O2745
Ph: (508) 995-1633
E-mail: 110310.1752@compuserve.com

Brechtel, Steve
Alberta Fish & Wildlife Division
9945-108 Street
Edmonton, AB T5K 2G6
Canada
Ph: (780) 422-9535
E-mail: steve.brechtel@gov.ab.ca

Britten, Mike
National Park Service
12795 Alameda Parkway
Denver, CO 80225
Ph: (303) 987-6705
E-mail: Mike_Britten@nps.gov

Brown, Nikolle, Wildlife Biologist
7779 N. Leonard
Clovis, CA 93611
Ph: (559) 298-8574
E-mail: black-catnik@worldnet.att.net

Brunson, Ken, Nongame Coordinator
Kansas Department of Wildlife and Parks
512 SE 25th Avenue
Pratt, KS 67124-8174
Ph: (316) 672-0792
E-mail: kenb@wp.state.ks.us

Burkett, Ester
California Department of Fish & Game
Wildlife Management Division
1416 Ninth Street
P.O. Box 944209
Sacramento, CA 95814

Busby, Bill, Associate Scientist
Kansas Biological Survey
2041 Constant Avenue
Lawrence, KS 66047
Ph: (785) 864-7692
E-mail: w.busby@falcon.cc.ukans.edu

Butts, Ken, Refuge Manager
U.S. Fish and Wildlife Service
Bitter Lake NWR
P.O. Box 7
Roswell, NM 88202-0007
Ph: (505) 622-6755 ext. 19
E-mail: Kenneth_Butts@fws.gov

Byer, Tim
Thunder Basin National Grassland
2250 E. Richards Street
Douglas, WY 82633
E-mail: tbyer/r2_mbr@fs.fed.us

Campbell, Erick, Wildlife Specialist
Bureau of Land Management
1340 Financial Boulevard, P.O. Box 12000
Reno, NV 89520-0006
Ph: (775) 861-6471
E-mail: Erick_Campbell@nv.blm.gov

Cannings, Dick
Bird Studies Canada
1330 Debeck Road, S. 11, C. 96, RR#1
Naramata, BC V0H 1N0
Canada
Ph: (250) 496-4049
E-mail: cannings@vip.net

Cerovski, Andrea, Nongame Bird Biologist
Wyoming Game & Fish Department
260 Buena Vista
Lander, WY 82520
Ph: (307) 332-7723 x232
E-mail: acerov@state.wy.us

Chavez-Ramirez, Felipe
Platte River Whooping Crane Maintenance Trust
6611 W. Whooping Crane Dr.
Wood River, NE 68883
Ph: (308) 384-4633
E-mail: fchavezramirez@aol.com

Chew, Lincoln
University of Lethbridge
4401 University Drive
Lethbridge, AB T1K 3M4
Canada
Ph: (403) 329-2245

Chynoweth, James, Wildlife Biologist
Cimarron National Grassland, US Forest Service
P.O. Box J
Elkhard, KS 67950
E-mail: jchynoweth/r2_psicc@fs.fed.us

Clayton, Kort
Thunderbird Wildlife Consulting, Inc.
P.O. Box 437
Wright, WY 82732-0437
Ph: (307) 464-6757
E-mail: clayton@vcn.com

Collister, Douglas, President
URSUS Ecosystem Management Ltd.
3426 Lane Crescent SW
Calgary, AB T3E 5X2
Canada
Ph: (403) 246-2697
E-mail: collis@telusplanet.net

Conrad, Shawn
Comanche National Grassland
P.O. Box 127
Springfield, CO 81073

Conway, Courtney
Arizona Cooperative Fish and Wildlife Research Unit
104 Bio Science East
University of Arizona
Tucson, AZ 85721
Ph: (520) 626-3775
E-mail: cconway@ag.arizona.edu

Corman, Troy, Neotropical Migratory Bird Coordinator
Arizona Game and Fish Department
2221 West Greenway Road
Phoenix, AZ 85023-4399
Ph: (602) 789-3508
E-mail: tcorman@gf.state.az.us

Cox, Nancy
4426 San Isidro NW
Albuquerque, NM 87107
Ph: (505) 345-2385
E-mail: sora@flash.net

Craig, Gerald
Colorado Division of Wildlife
317 West Prospect
Fort Collins, CO 80526-2003
Ph: (303) 297-1192
E-mail: Gerald.craig@state.co.us

Culbert, Doug
Alberta Environmental Protection, Natural History Section
Main Floor, North Tower, Petroleum Plaza
9945–108 Street
Edmonton, AB T5K 2G6
Canada
Ph: (403) 427-6750

Cummins, Eric
Washington Department of Fish & Wildlife
600 Capitol Way North
Olympia, WA 98501-1091

Dawson, Neil, Wildlife Assessment Program Leader
Ontario Ministry of Natural Resources, NW Region
25th Side Road, RR# 1
Thunder Bay, ON P7C 4T9
Canada
Ph: (807) 939-3120
E-mail: neil.dawson@mnr.gov.on.ca

Davis, Stephen
Acting Director
Watershed Monitoring & Assessment
SK Watershed Authority
101-2022 Cornwall St.
Regina, SK S4P 2K5
Ph: (306) 787-0711
E-mail: sdavis@wetland.sk.ca

DeSante, David, President
Institute for Bird Populations
P.O. Box 1346
Point Reyes Station, CA 94956
Ph: (415) 663-2052
E-mail: ddesante@birdpop.org

DeSmet, Ken, Endangered Species Biologist
Manitoba Natural Resources, Wildlife Branch
Box 520
Melita, MB R0M 1L0
Canada
Ph: (204) 522-3719
E-mail: kdesmet@gov.mb.ca

Desmond, Martha, Assistant Professor
Dept. of Fishery and Wildlife Sciences
NMSU, Campus Box 4901
P.O. Box 30003
Las Cruces, NM 88003-0003
Ph: (505) 646-1217
E-mail: mdesmond@nmsu.edu

Dillon, Jeff
U.S. Fish and Wildlife Service–ES
Oregon Fish and Wildlife Office
2600 S.E. 98th Avenue, Suite 100
Portland, OR 97266-1398
Ph: (503) 231-6179

Dinan, John J., Nongame Bird Program Manager
Nebraska Game and Parks Commission
2200 N. 33rd Street, P.O. Box 30370
Lincoln, NE 68503-0370
Ph: (402) 471-5440
E-mail: jdinan@ngpc.state.ne.us

Dinsmore, Jim
Iowa State University
Department of Animal Ecology
Aimes, IA 50011
Ph: (515) 294-7669
E-mail: Oldcoot@iastate.edu

Dose, Jennifer L.
Comanche National Grassland
P.O. Box 127
Springfield, CO 81073

Dowd Stukel, Eileen
South Dakota Dept. of Game, Fish & Parks
523 East Capitol Avenue
Pierre, SD 57501-3182
Ph: (605) 773-4229
E-mail: dowdstukel@state.sd.us

Dunning, Jr., John B.
Department of Forestry & Natural Resources
Purdue University
West Layfayette, IN 47907
Ph: (765) 494-3565
E-mail: bdunning@fnr.purdue.edu

Duxbury, Jason M.
Department of Renewable Resources
751 General Service Building
University of Alberta
Edmonton, AB T6J 4T8
Canada
Ph: (403) 951-8671
E-mail: Jason.duxbury@ec.gc.ca

Dyer, Orville
British Columbia Dept. of Environment & Parks
3547 Skaha Lake Road
Penticton, BC V2A 7K2
Canada
Ph: (604) 490-8244
Email: orville.dyer@gems4.gov.bc.ca

Eliason, Bonita
Minnesota Department of Natural Resources
500 Lafayette Road, Box 7
St. Paul, MN 55155
Ph: (612) 297-2276

Enderson, James H.
Department of Biology, Colorado College
Colorado Springs, CO 80903
Ph: (719) 389-6400
Email: Jenderson@cc.colorado.edu

Erickson, Carol
Fort Pierre National Grassland
124 S. Euclid Avenue, Box 417
Pierre, SD 57501

Espie, Rick, Wildlife Biologist
Saskatchewan Environment & Res. Mgmt.
Fish and Wildlife Branch, Room 436
Regina, SK S4S 5W6
Canada
Ph: (306) 787-2461
E-mail: rick.espie.erm@govmail.gov.sk.ca

Ethier, Thomas
Saskatchewan Museum of Natural History
Regina, SK S4P 3V
Canada
E-mail: tom.ethier@gems9.gov.bc.ca

Felskie, Heather
Saskatchewan Burrowing Owl Interpretive Center
Box 1467
Moose Jaw, SK S6H 4R3
Canada
Ph: (306) 692-8710
E-mail: sboic@sask.compatico.ca

Finley, Carol
Hawks Aloft, Inc.
P.O. Box 10028
Albuquerque, NM 87184

Finn, Jeff, Wildlife Biologist
California Department of Fish and Game
13515 Schooner Hill Drive
Gross Valley, CA 95945
Ph: (530) 477-0308
E-mail: jfinn@dfg.ca.gov

Foli, Gary
Little Missouri National Grassland
Box 8
Watford City, ND 58854
E-mail: gfoli/r1_dakotaprairie@fs.fed.us

Fox, Glen
877 Ridley Blvd.
Ottawa, ON K2A 3P4
Canada
Ph: (819) 997-6076
E-mail: glen.fox@ec.gc.ca

Fraser, James
Department of Fish & Wildlife Science
Virginia Polytechnic Institute
Blacksburg, VA 24061
Ph: (540) 231-6064
E-mail: fraser@vt.edu

Fredrickson, Larry, Wildlife Biologist
Department of Natural Resources
Crow Creek Sioux Tribe
P.O. Box 48
Fort Thomas, SD 57339
Ph: (605) 245-2187
E-mail: wildlife@rapidnet.com

Freilich, Jerry, Science Director
The Nature Conservancy
258 Main St., Suite 200
Lander, WY 82520
Ph: (307) 332-2973 ext. 3008
E-mail: jfreilich@rmisp.com

Fyfe, Richard
P.O. Box 3263
Fort Saskatchewan, AB T8L 2T2
Canada
Ph: (403) 998-9552
E-mail: fyferl@connect.ab.ca

Garza, Alfredo
Instituto de Ecologia
Centro Regional Durango
Apartado Postal 632
34000 Durango, DGO
Mexico

Gelvin-Innvaer, Lisa
Minnesota Department of Natural Resources
Nongame Wildlife Program (Region 4)
261 Hwy 15 South
New Ulm, MN 56073
Ph: (507) 359-6033
E-mail: lisa.gelvin-innvaer@dnr.state.mn.us

Gervais, Jennifer
Department of Fisheries and Wildlife
104 Nash Hall
Oregon State University
Corvallis, OR 97331

Geupel, Geoff, Landbird Program Coord.
Point Reyes Bird Observatory
4990 Shoreline Hwy.
Stinson Beach, CA 94970
Ph: (415) 868-1221
E-mail: ggeupel@prbo.org

Gifford, Dan, Wildlife Biologist
California Department of Fish and Game
1701 Nimbus Road
Rancho Cordova, CA 95670-4599
Ph: (916) 369-8851
E-mail: dgifford@dfg.ca.gov

Gilmer, David
USGS-BRD
6924 Tremont Road
Dixon, CA 95620
Ph: (707) 678-0682 ext. 614
E-mail: dave_gilmer@usgs.gov

Gilmore, Doug
Ontario Ministry of Natural Resources
Box 5003
Red Lake, ON P0V 2M0
Canada
Ph: (807) 727-1336
E-mail: doug.gilmore@mnr.gov.on.ca

Gould, Gordon
California Department of Fish & Game
Wildlife Management Division
P.O. Box 944209
Sacramento, CA 95814

Graham, Gary
Texas Parks and Wildlife Department
3000 IH 35 South, Suite 100
Austin, TX 78704

Grassel, Shaun, Wildlife Biologist
Lower Brule Sioux Tribe
Dept. of Wildlife, Fish, and Recreation
P.O. Box 246
Lower Brule, SD 57548
Ph: (605) 473-5666
E-mail: lbwfr@wcenet.com

Green, Mike, Landbird Biologist
US Fish and Wildlife Service
911 N.E. 11th Avenue
Portland, OR 97232
Ph: (503) 231-6164
E-mail: Michael_Green@fws.gov

Grensell, William
Nongame Bird and Mammal Section
California Department of Fish and Game
Wildlife Management Division
1416 Ninth Street
Sacramento, CA 95814
Ph: (916) 654-3828

Grettenberger, John
U.S. Fish and Wildlife Service
Endangered Species Consultation and Technical Asst. Branch
510 Desmond Drive SE, Suite 102
Lacey, WA 98503
Ph: (360) 753-6044
E-mail: John_Grettenberger@r1.fws.gov

Grissley, Kerry, Manager
Operation Grassland Community
Alberta Fish & Game Association
6924-104th St.
Edmonton, AB T6H 2L7
Canada
Ph: (780) 437-2342
E-mail: office@afga.org

Grondahl, Chris
North Dakota Game and Fish Department
100 N. Bismark Expressway
Bismark, ND 58501-5095
Ph: (701) 328-6612
E-mail: Cgrondah@state.nd.us

Haley, Katherine
Department of Fisheries and Wildlife
104 Nash Hall
Oregon State University
Corvallis, OR 97331

Hanebury, Lou, Wildlife Biologist
U.S. Fish and Wildlife Service
2900–4th Ave. N., Suite 301
Billings, MT 59101-1228
Ph: (541) 737-1957
E-mail: Lou_Hanebury@fws.gov

Harvey, Dwight
U.S. Fish and Wildlife Service, Listing Branch
Sacramento Fish and Wildlife Office
2800 Cottage Way, Room W-2605
Sacramento, CA 95825
Ph: (916) 414-6644
E-mail: Dwight_Harvey@fws.gov

Haug, Elizabeth, Biologist
P.O. Box 54, E R.R. 5
Saskatoon, SK S7K 3J8
Canada
Ph: (306) 975-9194
E-mail: Didiuka@sprint.ca

Hawkins, Cole
3612 Washoe Street
Davis, CA 95616-5087
Ph: (530) 753-1927
E-mail: chawkins@dcn.davis.ca.us

Hays, Dave, Endangered Species Specialist
Washington Department of Fish and Wildlife, Wildlife Diversity Division
600 Capitol Way N.
Olympia, WA 98501-1091
Ph: (360) 902-2366
E-mail: HAYSDWH@dfw.wa.gov

Hays, Loren
U.S. Fish and Wildlife Service, Listing and Recovery
2730 Loker Avenue West
Carlsbad, CA 92008
Ph: (760) 431-9440
E-mail: Loren_Hays@r1.fws.gov

Henderson, Carrol
Minnesota Department of Natural Resources
Nongame Wildlife Program
Box 7, 500 Lafayette Road
St. Paul, MN 55155
Ph: (651) 296-0700
E-mail: carro.henderson@dnr.state.mn.us

Herron, John
Texas Parks and Wildlife Department
3000 IH 35 South, Suite 100
Austin, TX 78704

Hetrick, Mindy
U.S. Fish & Wildlife Service
Rocky Mountain Arsenal NWR, Bldg. 120
Commerce, City CO 80022
Ph: (303) 289-0232
E-mail: mhetrick@rma.army.mil

Hickman, Melynda
Oklahoma Dept. of Wildlife Conservation
1801 North Lincoln Blvd.
Oklahoma City, OK 73105
Ph: (405) 521-4619

Hilliard, Mark, Wildlife Specialist
Bureau of Land Management
1387 South Vinnell Way
Boise, ID 83709-1657
Ph: (208) 373-4000
E-mail: Mark_Hilliard@blm.gov

Hinam, Heather
Department of Zoology
University of Manitoba
Winnipeg, MB R3T 2N2
Canada
Ph: (204) 253-7115
E-mail: umhinamh@cc.umanitoba.ca

Hjertaas, Dale
15 Olson Place
Regina, SK S4S 2J6
Canada
Ph: (306) 584-2835
E-mail: dale.hjertaas.erm@govmail.gov.sk.ca

Hodorff, Robert, Wildlife Biologist
Buffalo Gap National Grassland
Fall River Ranger District, U.S. Forest Service
209 N. River Street
Hot Springs, SD 57747
Ph: (605) 745-4107
E-mail: rhodorff@fs.fed.us

Holmes, Aaron
PRBO
4990 Shoreline Hwy.
Stinson Beach, CA 94970
Ph: (415) 868-1221

Holroyd, Geoffrey
Canadian Wildlife Service
4123–122 Street
Edmonton, AB T6J 1Z1
Canada
Ph: (780) 951-8689
E-mail: geoffrey.holroyd@ec.gc.ca

Holt, Denver
Owl Research Institute
P.O. Box 39
Charlo, MT 59824-0039
Ph: (406) 549-7626
E-mail: owl@montana.com

Howe, Frank, Nongame Avian Program Coordinator
Utah Division of Wildlife Resources
1594 W. North Temple, Suite 2110
P.O. Box 146301
Salt Lake City, UT 84114-6301
Ph: (801) 538-4764
E-mail: fhowe@state.ut.us

Howery, Mark, Nat. Res. Biologist
Oklahoma Dept. of Wildlife Conservation
Wildlife Diversity Program
1801 North Lincoln Blvd.
Oklahoma City, OK 73105
Ph: (405) 521-4619
E-mail: mhowery@odwc.state.ok.us

Hunt, W. Grainger
Predatory Bird Research Group
Marine Lab, University of California
Long Beach, CA 95064
Ph: (408) 459-2466
E-mail: grainger@cats.ucsc.edu

Hunter, Chuck
U.S. Fish and Wildlife Service
1875 Century Boulevard, Suite 420
Atlanta, GA 30345
Ph: (404) 679-7130
E-mail: Chuck_Hunter@fws.gov

Hutchings, Scott, Prairie Partner Coord.
Rocky Mountain Bird Observatory
13401 Piccadilly Road
Brighton, CO 80601
Ph: (303) 659-4348
E-mail: Scott.Hutchings@cbobirds.org

Ireland, Terry
Fish and Wildlife Enhancement
764 Horizon Drive, South Annex A
Grand Junction, CO 81506-3946
Ph: (970) 243-2778

Jacobson, Susan
U.S. Fish and Wildlife Service
P.O. Box 1306
Albuquerque, NM 87103
Phone: (505) 248-6655
E-mail: Susan_Jacobson@fws.gov

Jakubos, Bonnie
Bureau of Land Management
100 Oregon Street
Vale, OR 97918
Ph: (503) 473-3144

James, Paul
Saskatchewan Museum of Natural History
2340 Albert Street,Wascana Park
Regina, SK S4P 3V7
Canada
Ph: (306) 787-2798
E-mail: paul.james.erm@govmail.gov.sk.ca

Jaramillo, Alvaro
San Francisco Bay Bird Observatory
1290 Hope Street
P.O. Box 247
Alviso, CA 95002-0247
Ph: (408) 946-6548
E-mail: admin@sfbbo.org

Johnson, Douglas
USGS, Grasslands Ecosystem Initiative
Northern Prairie Wildlife Research Center
8711–37th Street, SE
Jamestown, ND 58401-7317
E-mail: Douglas_H_Johnson@usgs.gov

Kaltenecker, Greg, Director
Idaho Bird Observatory
Boise State University
Department of Biology
1910 University Drive
Boise, ID 83725-1515
Ph: (208) 426-3262

Knowles, Craig
Fauna West Wildlife Consultants
P.O. Box 113
Boulder, MT 59632
Ph: (406) 225-3221 or (406) 225-9118
E-mail: FaunaWest@aol.com

Kochert, Mike
USGS, Snake River Field Station
Forest/Rangeland Ecosystem Science Center
970 Lusk Street
Boise, ID 83706
Ph: (208) 426-5201
E-mail: mkochert@eagle.boisestate.edu

Korfanta, Nicole
School of Environment and Natural Resources
University of Wyoming
Laramie, WY 82071-3971
Ph: (307) 766-2068
E-mail: korfanta@uwyo.edu

LeCaptain, Leonard
U.S. Fish and Wildlife Service
Ecological Services
6610 Washburn Way
Klamath Falls, OR 97603

Leupin, Ernest
Centre for Applied Conservation, U.B.C.
1405 Cariboo Hwy.
Williams Lake, BC V2G 2W3
Canada
Ph: (250) 392-2358
E-mail: leupin@direct.ca

Lewis, Steve A., Project Leader
Klamath Falls Fish and Wildlife Office
6610 Washburn Way
Klamath Falls, OR 97603-9365
Ph: (541) 885-8481

Lewis, Steve J.
Nongame Migratory Bird Coordinator
U.S. Fish and Wildlife Service
Federal Building, 1 Federal Drive
Ft. Snelling, MN 55111-4056
Ph: (612) 713-5473
E-mail: Steve_J_Lewis@fws.gov

Lorentzen, Ed
Bureau of Land Management
2800 Cottage Way
Sacramento, CA 95825-1886
Ph: (916) 978-4646
E-mail: Edward_Lorentzen@ca.blm.gov

Low, Dave
Ministry of Environment
British Columbia Government, Lands and Parks
1259 Dalhousie
Kamloops, BC V2C 5Z5
Canada
Ph: (250) 371-6243
E-mail: dlow@kamloops.env.gov.bc.ca

Lutz, Scott, Assistant Professor
Department of Wildlife Ecology
University of Wisconsin, 226 Russell Labs
1630 Linden Drive
Madison, WI 53706-1598
Ph: (608) 263-8979
E-mail: rslute@facstaff.wisc.edu

Martell, Mark, Cons. Programs Coord.
The Raptor Center
College of Veterinary Medicine
St. Paul, MN 55108
Ph: (612) 624-9790
E-mail: marte006@tc.umn.edu

Marti, Carl, Raptor Research Center
Boise State University
Boise, ID 83725
Ph: (208) 426-6996

Martin, Catrina, Assistant Field Supervisor
U.S. Fish and Wildlife Service, North Coast
2493 Portola Road, Suite B
Ventura, CA 93003
Ph: (805) 644-1766
E-mail: Catrina_Martin@r1.fws.gov

Martin, Roy
California Dept. of Parks & Recreation
Resource Protection Division
P.O. Box 450
Sacramento, CA 94296
Ph: (916) 653-3591

Mazur, Kurt
Grassland and Forest Bird Project
Partners in Flight Manitoba
200 Saulteaux Cresent, Box 24
Winnipeg, MB R3J 3W3
Canada
Ph: (204) 945-6816
E-mail: kmazur@nr.gov.mb.ca

McCluskey, Cal, Sr. Wildlife Specialist
BLM, Fish, Wildlife and Forests Group
1387 S. Vinnell Way
Boise, ID 83709
Ph: (208) 373-4042
E-mail: cmcclusk@id.blm.gov

McKeever, Katherine
The Owl Foundation
4117 21st. Street
Vineland Station, ON L0R 2E0
Canada
Ph: (905) 562-5986

Mealey, Brian Keith
Miami Museum of Science
3280 South Miami Avenue
Miami, FL 33129
Ph: (305) 854-4247 ext. 256
E-mail: 6mealey@miamisci.org

Mehlman, David, Dir. of Cons. Programs
Wings of the Americas
322 Tyler Road NW
Albuquerque, NM 87107
Ph: (505) 344-1732
E-mail: dmehlman@tnc.org

Mele, Gary
4536 Alpine Road
Portola Valley, CA 94028

Melquist, Wayne
Idaho Department of Fish and Game
600 South Walnut, P.O. Box 25
Boise, ID 83707
Ph: (208) 334-2676
E-mail: Wmelquis@idfg.state.id.us

Mesta, Robert, Coordinator
USFWS, Sonoran Desert Joint Venture
12661 E. Broadway Blvd.
Tucson, AZ 85748
Ph: (520) 722-4289
E-mail: Robert_Mesta@fws.gov

Miller, Edwin J.
Kansas Department of Wildlife & Parks
5089 Co. Road 2925
Independence, KS 67301

Miller, Jeff
Center for Biological Diversity
P.O. Box 40090
Berkley, CA 94704
Ph: (510) 841-0812
E-mail: jmiller@biologicaldiversity.org

Millsap, Brian
Division of Migratory Bird Management
U.S. Fish and Wildlife Service
4401 N. Fairfax Drive MS 634
Arlington, VA 22203
E-mail: Brian_Millsap@fws.gov

Moravek, Glen
Fort Pierre National Grassland
124 S. Euclid Avenue, Box 417
Pierre, SD 57501
E-mail: gmoravek/r2_nebraska@fs.fed.us

Murphy, Robert, Wildlife Biologist
U.S. Fish and Wildlife Service
Lostwood National Wildlife Refuge
8315 Highway 8
Kenmare, ND 58746-9046
Ph: (701) 848-2722
E-mail: Bob_Murphy@fws.gov

Neal, Larry
Nevada Division of Wildlife
1100 Valley Road
Reno, NV 89512-2817

Nevada Breeding Bird Atlas
Great Basin Bird Observatory
One East First Street, Suite 500
Reno, NV 89501
Ph: (775) 348-2644
E-mail: gbbo@altavista.com

Nugent, Martin
Oregon Department of Fish and Wildlife
Wildlife Diversity Program
2501 SW First Avenue, P.O. Box 59
Portland, OR 97207
Ph: (503) 872-5260 x5346
E-mail: Martin.Nugent@state.or.us

Oakleaf, Bob, Nongame Coordinator
Wyoming Game and Fish Department
260 Buena Vista
Lander, WY 82520
Ph: (307) 332-2688
E-mail: roakle@missc.state.wy.us

Oliphant, Lynn
Department of Vet. Anatomy
University of Saskatchewan
Saskatoon, SK S7N 0W0
Canada

Olson, Mike
U.S. Fish and Wildlife Service, Ecological Services
3425 Miriam Avenue
Bismarck, ND 58501-7926
Ph: (701) 250-4481
E-mail: Michael_Olson@fws.gov

Ortega-Rubio, Alfredo
Centro de Investigaciones Biologicas, Div. Biol. Terr.
APDO Postal 128
La Paz, B.C.S. 23000
Mexico

Palermo, Kerrie, State Office Biologist
Bureau of Land Management
P.O. Box 2965
Portland, OR 97208
Ph: (503) 952-6382
E-mail: OSO_Wildlife_Biologist_Mail@or.blm.gov

Parrish, Jim, Coordinator
Utah Partners in Flight Program
Utah Division of Wildlife Resources
1594 West North Temple, Suite 2222
Salt Lake City, UT 84116
Ph: (801) 538-4788
E-mail: Nrdwr.jparrish@state.ut.us

Pence, Diane
US Fish and Wildlife Service
300 Westgate Center Drive
Hadley, MA 01035
Ph: (413) 253-8577
E-mail: Diane_Pence@fws.gov

Peregrine Fund
566 W Flying Hawk Lane
Boise, ID 83709
Ph: (208) 362-3716

Pezzolesi, Linda
Department of Biological Sciences
Binghamton University
P.O. Box 6000
Binghamton, NY 13902-6000
Ph: (607) 777-2438

Plumpton, David, Wildlife Biologist
H.T. Harvey & Associates
3150 Almaden Expressway, Suite 145
San Jose, CA 95118
Ph: (408) 448-9450 ext. 204
E-mail: dplumpton@harveyecology.com

Poulin, Ray G.
Department of Biology
University of Regina
Regina, SK S4S 0A2
Canada
Ph: (306) 585-4562
E-mail: poulinr@uregina.ca

Priestley, Lisa
Bird Studies Canada
Environment Canada
Room 200
4999-98 Avenue
Edmonton, Alberta, T6B 2X3 Canada

Quinlan, Richard
Regional Biologist
Species at Risk Program
Alberta Fish and Wildlife
2nd Flr, YPM Place 530 – 8 St. S.
Lethbridge, Alberta, T1J 2J8
Ph: (403) 381-5397
E-mail: Richard.Quinlan@gov.ab.ca

Rangel-Salazar, Jose-Luis
Museo de Zoologica Iztacala
ENEP UNAM IZTACALA
Apartado Postal 314
Tlalnepantla, 54090
Mexico
E-mail: Penrique@yahoo.com

Ratcliff, Brian
307 Dog Lake Road, RR #12, Site 15-22
Thunderbay, ON P7B 5E3
Canada
Ph: (807) 768-8408
E-mail: brat@nomin.norlink.net

Ratti, John
Department of Wildlife Resources
University of Idaho
Moscow, ID 83844-1136
Ph: (208) 885-7741

Rau, Larry
Bureau of Land Management
111 Garryowen Road
Miles City, MT 59301
E-mail: Larry_Rau@blm.gov

Reinking, Dan, Atlas Coordinator
Sutton Avian Research Center
P.O. Box 2007
Bartlesville, OK 74005-2007
Ph: (918) 336-7778
E-mail: www.suttoncenter.org

Restani, Marco
Ecosystem Science & Conservation Div.
University of Washington
College of Forest Resources, Box 352100
Seattle, WA 98195-2100
Ph: (206) 543-2764
E-mail: restani@u.washington.edu

Rodrigues-Estrella, Ricardo
Centro de Investigaciones Biologicas
Div. Biol. Terr.,
Apartado Postal 128
La Paz, B.C.S. 23000
Mexico

Ronan, Noelle
Department of Fisheries and Wildlife
104 Nash Hall
Oregon State University
Corvallis, OR 97331

Roscoe, Terry, Wildlife Biologist
1701 Nimbus Road
Rancho Cordova, CA 95670-4599
Phone: (916) 358-2876
E-mail: troscoe@dfg.ca.gov

Rosenberg, Daniel K.
Department of Forest, Range, and Wildlife Sciences
Utah State University
5230 Old Main Hill
Logan, UT 84322-5230
Phone: (435) 797-8167
E-mail: dan.rosenberg@usu.edu

Ruckeles, Ann
Colorado Natural Heritage
850 37th Street
Boulder, CO 80303

Sallabanks, Rex
Idaho Department of Fish & Game
600 S. Walnut
Boise, ID 83707

Sample, David
Wisconsin DNR
1350 Femrite Drive
Monona, WI 53716

Saslaw, Larry, Wildlife Mgmt. Biologist
Bureau of Land Management
3801 Pegasus Drive
Bakersfield, CA 93308
Ph: (661) 391-6000
E-mail: Lawrence_Saslaw@ca.blm.gov

Schlafmann, Deb
U.S. Fish and Wildlife Service
2800 Cottage Way, Room W-2605
Sacramento, CA 95825
Ph: (916) 414-6600
E-mail: Debra_Schlafmann@fws.gov

Scobie, Dave, Principle
Avocet Environmental Inc.
P.O. Box 1644
Brooks, AB T1R 1C5
Canada
Ph: (403) 793-8500
E-mail: avocet@eidnet.org

Sebesta, Dawn
HawkWatch International
2466 Meadows Drive
Park City, UT 84060-7032
Ph: (435) 649-3024
E-mail: stoney@pcfastnet.com

Shackelford, Clifford, Nongame Ornithologist
Texas Parks and Wildlife Department
3000 IH 35 South, Suite 100
Austin, TX 78704
Ph: (512) 912-7045
E-mail: clifford.shackelford@tpwd.state.tx.us

Shackford, John
429 Oak Cliff Drive
Edmond, OK 73034-8262
Ph: (405) 340-5057
E-mail: johnsshack@aol.com

Sherrod, Steve
Sutton Avian Research Center
P.O. Box 2007
Bartlesville, OK 74005
Ph: (918) 336-7778
E-mail: gmsarc@aol.com

Shyry, Darcey
11524 44th Ave.
Edmonton, AB T6J 0Z5
Canada
Ph: (780) 435-2335
E-mail: darceyshyry@hotmail.com

Sidle, John, TES Coordinator
Great Plains National Grasslands
USDA–Forest Service
125 North Main Street
Chadron, NE 69337
Ph: (308) 432-0300
E-mail: jsidle@fs.fed.us

Silcock, Ross
P.O. Box 57
Tabor, IA 51653
E-mail:silcock@rosssilcock.com

Skeel, Margaret, Program Coordinator
Nature Saskatchewan
1860 Lorne St., Room 206
Regina, SK S4P 2L7
Canada
Ph: (306) 780-9273
E-mail: nature.sask@unibase.com

Skiba, Gary
Colorado Division of Wildlife
6060 Broadway
Denver, CO 80216
Ph: (303) 291-7466
E-mail: Gary.skiba@state.co.us

Skoruppa, Mary Kay, Biologist
USGS, Biological Resource Division
6300 Ocean Drive
TAMU-CC Box 339
Corpus Christi, TX 78412
Ph: (361) 985-6266
E-mail: Mary_Kay_Skoruppa@usgs.gov

Snake River Basin Office
1387 S. Vinnell Way, Room 368
Boise, ID 83709
Ph: (208) 378-5243

Steenhof, Karen, Res. Wildlife Biologist
USGS, Snake River Field Station
970 Lusk Street
Boise, ID 83706
Ph: (208) 426-5206 or (208) 331-5206
E-mail: ksteenho@eagle.boisestate.edu

Stepnisky, Dave
Renewable Resources, University of Alberta
18516-84 Avenue
Edmonton, AB T5T 1G5
Canada
E-mail: dstepnisky@excite.com

Svingen, Dan Grassland Biologist
U.S. Forest Service
240 W. Century Avenue
Bismarck, ND 58501
Ph: (701) 50 4463 ext. 107
E-mail: dsvingen@fs.fed.us

Thompson, Bruce
Coop. Fish & Wildlife Research Unit
New Mexico State University
P.O. Box 30003, Department 4901
Las Cruces, NM 88003
Ph: (505) 646-6093
E-mail: Bthompso@nmsu.edu

Trapp, John
US Fish and Wildlife Service
Office of Migratory Bird Management
4401 N. Fairfax Drive, Suite 634
Arlington, VA 22203
Ph: (703) 358-1821
E-mail: John_Trapp@fws.gov

Trefry, Helen
P.O. Box 176, Site 1, R.R. #2
Tofield, AB T0B 4J0
Canada
Ph: (780) 951-8693
E-mail: helen.trefry@ec.gc.ca

Turner, Annette
Hawk Mountain Sanctuary
1700 Hawk Mountain Road
Kempton, PA 19529

Uhmann, Tanys
Natural Resources Institute
University of Manitoba
70 Dysart Road
Winnipeg, MB 3T 2N2
Canada
Ph: (204) 269-2184
E-mail: umuhmann@cc.umanitoba.ca

Van de Hoek, Robert
Bureau of Land Management
4301 Rosedale Highway
Bakersfield, CA 93308

VerCauteren, Tammy
Rocky Mountain Bird Observatory
13401 Piccadilly Road
Brighton, CO 80601
Ph: (303) 659-4348
E-mail: Tammy.vercauteren@rmbo.org

Vermillion, Bill
Louisiana Natural Heritage Program
Department of Wildlife & Fisheries
P.O. Box 98000
Baton Rouge, LA 70898-9000
Ph: (225) 765-2976
E-mail: Vermillion_wg@wlf.state.la.us

Wallace, George
American Bird Conservancy
P.O. Box 249
4249 Loudoun Avenue
The Plains, VA 20198
Ph: (540) 253-5780
E-mail: gwallace@abcbirds.org

Waller, David, Wildlife Biologist
Bureau of Land Management
Glasgow Field Station, Route #1-4775
Glasgow, MT 59230-9796
Phone: (406) 228-3762
E-mail: david_waller@blm.gov.

Walton, Brian, Coordinator
Predatory Bird Research Group
Long Marine Lab, University of California
Santa Cruz, CA 95060
Ph: (831) 459-2466
E-mail: Walton@cats.ucsc.edu

Warnock, Robert, Research Scientist
Nature Saskatchewan
4107 McPhail Avenue
Regina, SK S4S 1G1
Canada
Ph: (306) 586-2492
E-mail: warnock@accesscomm.ca

Wedgwood, Jim
610 Leslie Avenue
Saskatoon, SK 57H 222
Canada

Weir, Colin
P.O. Box 1150
Coaldale, AB T1M 1M9
Canada
Ph: (403) 345-4262
E-mail: Cweir@telusplanet.net

Wellicome, Troy
Environment Canada
Canadian Wildlife Service
4999-98 Avenue, Room 200
Edmonton, AB T6B 2X3
Canada
Ph: (780) 951-8671
E-mail: Troy.wellicome@ec.gc.ca

Williams, Bob, State Supervisor
U.S. Fish and Wildlife Service
1340 Financial Boulevard, Suite 234
Reno, NV 89502-7147
Ph: (775) 861-6331
E-mail: Bob_D_Williams@r1.fws.gov

Williams, Sandy
New Mexico Game and Fish Department
Nongame Wildlife Program
Villagra Building, P.O. Box 25112
Santa Fe, NM 87504
Ph: (505) 827-7911
E-mail: SOWilliams@state.nm.us

Wise, Cathryn, Nongame Birds Biologist
Arizona Game and Fish Department
2221 W. Greenway Rd.
Phoenix, AZ 85023
Ph: (602) 789-3577
E-mail: cwise@gf.state.az.us

Wohl, Kent
Nongame Migratory Bird Coordinator
US Fish and Wildlife Service
1101 East Tudor Road
Anchorage, AL 99503
Ph: (907) 786-3503
E-mail: Kent_Wohl@fws.gov

Woodin, Marc, Wildlife Biologist
6300 Ocean Drive, TAMU-CC Box 339
Corpus Cristi, TX 78412
Ph: (361) 985-6266
E-mail: marc_woodin@usgs.gov

Yamamoto, Julie
California Environmental Protection Agency
OEHHA, 301 Capitol Mall, Room 205
Sacramento, CA 95814
Ph: (916) 323-9538
E-mail: Jyamamot@oehha.ca.gov

Zohrer, Jim
Iowa Dept. of Natural Resources
Wallace State Office Bldg.
Des Moines, IA 50319

Appendix D: Scientific and Common Names of Animals and Plants Mentioned in the Burrowing Owl Status Assessment and Conservation Plan

Table D-1: Scientific and common names of animals mentioned in the "Status Assessment and Conservation Plan for the Western Burrowing Owl in the United States".

Scientific Name	Common Name
Accipiter cooperii	Cooper's Hawk
Athene cunicularia floridana	Florida Burrowing Owl
Athene cunicularia hypugaea	Western Burrowing Owl
Bubo virginianus	Great-horned Owl
Buteo jaimaicensis	Red-tailed Hawk
Buteo regalis	Ferruginous Hawk
Buteo swainsoni	Swainson's Hawk
Canis familiaris	Domestic dog
Canis latrans	Coyote
Circus cyaneus	Northern Harrier
Corvus brachyrhynchos	American Crow
Cynomys ludovicianus	Black-tailed prairie dog
Cynomys gunnisoni	Gunnison's prairie dog
Cynomys leucurus	White-tailed prairie dog
Dasypus novemcinctus	Nine-banded armadillo
Dipodomys ordii	Ord kangaroo rat
Dipodomys spectabilis	Banner-tailed kangaroo rat
Dipodomys spp.	Kangaroo rat
Eremophila alpestris	Horned Lark
Falco columbarius	Merlin
Falco mexicanus	Prairie Falcon
Falco peregrinus	Peregrine Falcon
Falco sparverius	American Kestrel
Felis catus	Domestic cat
Gopherus agassizii	Desert tortoise
Gopherus polyphemus	Gopher tortoise
Haliaeetus leucocephalus	Bald Eagle
Lynx rufus	Bobcat
Marmota flaviventris	Yellow-bellied marmot
Marmota monax	Woodchuck
Mephitis spp.	Skunk
Microtus californicus	Meadow vole
Microtus montanus	Montane vole

Table D-1: Continued

Scientific Name	Common Name
Mustela nigripes	Black-footed ferret
Mustela spp.	Weasel
Peromyscus leucopus	White-footed mouse
Peromyscus maniculatus	Deer mouse
Reithrodontomys megalotis	Western harvest mouse
Solenopsis wagneri	Fire ant
Spermophilus columbianus	Columbian ground squirrel
Spermophilus douglasii	Douglas's ground squirrel
Spermophilus richardsonii	Richardson's ground squirrel
Spermophilus spilosoma	Spotted ground squirrel
Spermophilus tereticaudus	Round-tailed ground squirrel
Spermophilus tridecemlineatus	Thirteen-lined ground squirrel
Spermophilus variegatus	Rock squirrel
Taxidea taxus	Badger
Thomomys spp.	Pocket gophers
Tyto alba	Barn Owl
Vulpes spp., *Urocyon cineroargenteus*	Foxes

Table D-2: Scientific and common names of plants mentioned in the "Status Assessment and Conservation Plan for the Western Burrowing Owl in the United States".

Scientific Name	Common Name
Agropyron spicatum	Bluebunch wheatgrass
Artemisia tridentata	Big sagebrush
Atriplex polycarpa	Saltbush
Bouteloua gracilis	Blue grama
Bromus tectorum	Downy brome, Cheatgrass
Buchloe dactyloides	Buffalograss
Chrysothamnus nauseosus	Rabbit brush
Gutierrezia sarothrae	Snakeweed
Halogeton glomeratus	Halogeton
Larrea divaricata	Creosote bush
Oryzopsis contracta	Indian ricegrass
Pinus edulis	Pinyon pine
Pinus ponderosa	Ponderosa pine
Poa sandbergii	Sandberg bluegrass
Prosopis spp.	Mesquite
Purshia tridentata	Antelope bitterbrush
Sarcobatus vermiculatus	Greasewood
Salsola tragus	Russian thistle
Stipa comata	Needle and thread
Tamarix ramosissima	Tamarisk

U.S. Department of the Interior
U.S. Fish & Wildlife Service
Route 1, Box 166
Sheperdstown, WV 25443

http://www.fws.gov

June 2003

Modern Insect Extinctions, the Neglected Majority

ROBERT R. DUNN*

Ecology and Evolutionary Biology, 569 Dabney Hall, University of Tennessee, Knoxville, TN 37996, U.S.A., email rdunn1@utk.edu

Abstract: *Most extinctions estimated to have occurred in the historical past, or predicted to occur in the future, are of insects. Despite this, the study of insect extinctions has been neglected. Only 70 modern insect extinctions have been documented, although thousands are estimated to have occurred. By focusing on some of the 70 documented extinctions as case studies, I considered ways in which insect extinctions may differ from those of other taxa. These case studies suggested that two types of extinction might be common for insects but rare for other taxa: extinction of narrow habitat specialists and coextinctions of affiliates with the extinctions of their hosts. Importantly, both of these forms of extinction are often ignored by conservation programs focused on vertebrates and plants. Anecdotal evidence and recent simulations suggest that many insect extinctions may have already occurred because of loss of narrow habitat specialists from restricted habitats and the loss of hosts. If we are serious about insect conservation, we need to spend more time and money documenting such extinctions. To neglect such extinctions is to ignore the majority of species that are or were in need of conservation.*

Key Words: coextinction, extinction rates, parasites

Extinciones Modernas de Insectos, la Mayoría Desatendida

Resumen: *La mayoría de las extinciones que se estima han ocurrido en el pasado histórico, o que se predice ocurrirán en el futuro, son de insectos. No obstante lo anterior, se ha desatendido el estudio de las extinciones de insectos. Sólo se han documentado 70 extinciones modernas de insectos, aunque se estima que han ocurrido miles. Concentrándome en algunas de las 70 extinciones documentadas como estudios de caso, consideré formas en que pueden diferir las extinciones de insectos de las de otros taxa. Estos estudios de caso sugirieron dos tipos de extinción que pueden ser comunes para insectos pero raros para otros taxa: extinción de especialistas de hábitat y coextinciones de afiliados con las extinciones de sus hospederos. De manera considerable, ambas formas de extinción a menudo son ignoradas por programas de conservación centrados en vertebrados y plantas. Evidencia anecdótica y simulaciones recientes sugieren que ya pueden haber ocurrido muchas extinciones de insectos debido a la pérdida de especialistas de hábitat en hábitats restringidos y la pérdida de hospederos. Si somos serios con la conservación de insectos, necesitamos más tiempo y dinero para documentar tales extinciones. Desatender tales extinciones es ignorar a la mayoría de especies que están o estuvieron en necesidad de ser conservados.*

Palabras Clave: coextinción, parásitos, tasas de extinción

Introduction

Knowing how many species we are extinguishing is a basic aspect of our planetary inventory. Pimm and Raven (2000) estimated that 100,000 of every million species could be extinct by 2050 because of habitat loss. What is often glossed over in such estimates is that most of these extinctions are likely to be of insects (Kellert 1993). If 57% of metazoan species are insects (e.g., Stork 1997), Pimm and Raven's estimate equates to 57,000 insect extinctions per million species on Earth in the next 50 years. Other estimates, such as those by Thomas et al. (2004), would yield higher estimates of insect extinctions. The biodiversity crisis is undeniably an insect biodiversity crisis. Yet

*Current address: Department of Zoology, North Carolina State University, Box 7617, 3213 Gardner, Raleigh, NC 27695-7617.
Paper submitted March 1, 2004; revised manuscript accepted September 13, 2004.

Conservation Biology 1030–1036
©2005 Society for Conservation Biology
DOI: 10.1111/j.1523-1739.2005.00078.x

insect conservation remains the awkward "kid sister" to vertebrate conservation. Nowhere is this clearer than in what we know, or rather do not know, about insect extinction, particularly for those extinctions that may have already occurred.

If we assume insects have gone extinct at similar rates to other taxa over the last 500 years, we can estimate the number of insect extinctions over that time period based on the extinction rate for well-known taxa. Over the last 600 years 129 bird extinctions, 1.3% of all bird species, were documented (IUCN 2002). Given, say, 3.4 million insect species, we expect roughly 44,000 insect extinctions to have occurred in the last 600 years (see similar estimates in Kellert 1993); 70 insect extinctions were documented over that time period. Considering lists of endangered species reveals a similar discrepancy. Only 37 insect species are currently listed as endangered or threatened in the United States by the Environmental Protection Agency (Redak 2000). If the same proportion of insects were as endangered as vertebrates, we would predict 29,000 endangered or threatened insects in North America (Redak 2000), a possibility that the U.S. Endangered Species Act is incapable of dealing with.

If the above estimates of the number of insect extinctions and the underlying assumption that insect extinction rates are similar to those of other taxa are accurate to even two orders of magnitude, we have missed almost all insect extinctions (and are missing most endangered insects). If such estimates are wrong, we are grossly misjudging how many species are currently at risk of extinction. Understanding the discrepancy between estimated and observed insect extinction rates thus seems worth considering. What accounts for the tens of thousands of expected but undocumented insect extinctions? What does this discrepancy mean? How important is it to our understanding of extinction and the future of ecosystems? These should be questions at the heart of species conservation, yet they have hardly been addressed. No peer-reviewed articles have been published reviewing modern insect extinctions, and no estimates of global extinction rates have explicitly focused on insects. Here I take a case-study approach to address whether and why insect extinctions might differ from those of better-studied taxa and how we might better estimate the magnitude of insect extinctions. The extinct insects do not form a data set per se because we have documented so few. Nonetheless, we may be able to learn a fair amount from them.

The "Data Set" of Extinct Insects

Little has been recorded about the demise of extinct insect species, even for observed extinctions. The only information in the IUCN database for extinct insects consists of the country and region in which it lived and sometimes the year in which it was described. Outside of the IUCN database, additional information on these species is scarce, typically consisting of only the original description of the species and a few lines in a subsequent revision of the group. Occasionally authors considered the causes of an extinct insect species' demise (e.g., Rentz 1977; Liebherr & Polhemis 1997; McCafferty 2001), although even in these cases no additional information was incorporated into the IUCN database.

Undoubtedly one reason so few insect extinctions have been documented is understudy. Fewer than half of all metazoan species are described, and even for described insect species most are known from a single specimen and site (Stork 1997). Even for large insect species on small islands, documenting extinction with any certainty is difficult because so little is known about the habitat preference and seasonality of most insect species (e.g., Priddel et al. 2003). Many scientists know of insect species they assume are extinct, but they have not been able to search for them with the conclusiveness the IUCN list requires. Sometimes these "missing" species make it into publications (e.g., McCafferty 2001) before they are listed as extinct, but more often than not these missing species are known only by the experts on the group. The difficulty in documenting insect extinctions is apparent even within the insect extinctions that have been documented (Stork 1997; McKinney 1999). Most documented insect extinctions are from well-studied taxa in well-studied regions (Mawdsley & Stork 1995), simply because these are the species whose absences we are capable of noticing. Fifty-five of the documented extinctions are from the United States. Thirty-eight of these extinctions are from Hawaii, an island group that is exceptional only in that it was studied early enough to document insects before they were gone (Priddel et al. 2003). Insect extinction rates could be higher on islands than on mainlands, as is the case for birds (e.g., Manne et al. 1999), but habitats on islands may also just be easier to search completely (Mawdsley & Stork 1995). Most of the documented extinct insect species not from Hawaii are from continental North America (IUCN 2002). Taxonomically, most observed insect extinctions are from charismatic clades (Mawdsley & Stork 1995). More than half of all recently documented insect extinctions are of Lepidoptera (37 species; IUCN 2002), arguably the best-studied insect taxon.

Although the difficulty of studying insect extinction may account for much of the discrepancy between expected and observed extinction rates for insects, it may not be the whole story. Some evidence suggests that insects may actually be less extinction prone than other taxa or at risk from different factors than other taxa. Even insect taxa that have been relatively well studied show lower rates of historical extinction in the United States than birds over the same time period. We have not yet succeeded in extinguishing even 1 of the roughly 111 species of tiger beetles collected in the continental United States

(although several are close; Pearson & Cassola 1992), and we have not extinguished any species of odonates from the same region (Liebherr & Polhemis 1997). Only one species of Macrolepidoptera in the United States appears to have gone extinct (IUCN 2002). Mawdsley and Stork (1995) calculated future extinction rates of a variety of taxa based on lists of endangered species. They predicted that for the United Kingdom regional extinction rates for insects are one-fourth to one-tenth those of birds (Mawdsley & Stork 1995). Although even a 10-fold difference in the extinction rates of birds and insects does not nearly account for the differences between estimates and observed numbers of insect extinctions, it suggests insect extinctions may differ in important ways from those of birds and mammals.

Insect extinctions might differ in rate and other attributes from those of other taxa for a variety of reasons. Because of their small size, insects might require smaller total habitat areas for a given population size (e.g., Blackburn & Gaston 1997). Alternatively, the factors driving insect extinctions may differ in both kind and relative importance from those driving the extinctions of other taxa. Many documented insect extinctions appear to be due to the same factors that drive vertebrate extinctions and hence represent extinctions that could be prevented by conservation measures targeted at vertebrates. For example, eight Singaporean species of phasmids appear to have gone extinct because of the same habitat loss and overharvest (for medicines) affecting vertebrates in the region (Seow-Choen 1997). Aquatic insects, like aquatic vertebrates, are particularly at risk, with four mayflies likely extinct from the United States alone (McCafferty 2001). Other documented insect extinctions, however, are due to factors likely to play only a minor role in the extinctions of vertebrates or plants or occur in places or at spatial scales different from those of vertebrates and plants. The list of documented insect extinctions contains apparent examples of both extinctions of extremely narrow habitat specialists and coextinctions (extinction of affiliates with the extinction of their hosts). Importantly, both these groups of extinct species are likely to be missed by conservation plans and studies directed at vertebrates and plants. Thus, I focused on these forms of extinction in insects, their potential significance, and how we might better quantify their magnitude.

Narrow Habitat Specialists

The Antioch sand dunes are an emblematic case study in the extinction of narrow habitat specialists from restricted habitats, typically not considered for conservation. The Antioch Dunes in California (U.S.A.) were originally contiguous with the Mohave Desert to the south. Prehistorically, climatic changes isolated the dunes from the Mohave Desert and thus isolated the species that lived on the dunes. As a result, the species in the sand dunes are not coastal dune species but desert species, many of which are endemic to the sand dunes. Historically, the dunes stretched roughly 9 km along the San Joaquin River. Fewer than 22 ha of this original habitat remain (USFWS 2001).

In the 1960s, Dave Rentz found one individual of a new species, *Neduba* sp., in a specimen drawer. The specimen had been collected years earlier on the Antioch Dunes but never described. The new species was unique in the morphology of its genitalia and its size. Rentz went to the Antioch Dunes but could find no living individuals. After several years of searching, he described the species as *Neduba extincta*, the extinct neduba katydid and it was put on the IUCN list of extinct species (Rentz 1977). Not long thereafter, entomologists began to look for other historically recorded insect taxa on the sand dunes (Powell 1978; USFWS 2001). We now know there were at least eight insect species endemic to the dunes. Three of those species, *N. extincta*, Antioch robber fly (*Cophura hurdi*), and Antioch sphecid wasp (*Philanthus nasalis*), appear to be extinct (e.g., Powell 1978). The remaining species are listed as endangered or are proposed for listing, but by any measure they are threatened (USFWS 2001).

The story of the Antioch Dunes is not an isolated one. It instead seems to represent what has probably occurred or is occurring in many isolated habitats that, like Antioch, are too small to have endemic vertebrates but not too small for endemic insects (e.g., Powell 1978). Vertebrate conservation plans or plans based on vegetation type would probably not have conserved any of the Antioch Dune endemic insects because no vertebrate or plant species are endemic to the dunes.

Fortunately, the Antioch site is protected now, because of the presence of an endemic butterfly subspecies and an endemic plant subspecies (Powell 1978; Mattoni et al. 2000; USFWS 2001). In many cases habitats with endemic insects but few or no endemic vertebrates or plants are ignored and unprotected. Recent studies of sand plain habitats in Connecticut (U.S.A.) included on the National Vegetation Classification System as "sparsely vegetated sand dunes" revealed a diversity of insect species apparently restricted to particular sand dune types not distinguishable based on vegetation (D. Wagner, unpublished data). Few plant species are endemic to these habitats and in many cases the plant species are primarily invasive, yet from an entomological perspective these habitats should be some of the most important conservation targets in New England. They remain unprotected even though the cost of conserving such reduced habitat types is often relatively small (e.g., USFWS 2001), particularly when compared to the millions of dollars that can be spent each year on captive breeding programs for individual vertebrate species (e.g., the Californian Condor [*Gymnogyps californianus*]; Snyder et al. 1996).

The Antioch sand dunes and the New England sand dune systems are two cases where insects appear to

have both narrower and spatially different habitat requirements than do vertebrates and plants. Insects may generally be more likely to have narrower habitat specificities or different spatial patterns of habitat specificities than other taxa (and hence be at greater risk of extinction or in need of different conservation measures). Insect species might be expected to have smaller geographic ranges than other taxa if they are able to pack more individuals into a smaller area, have a smaller geographic range for a given population size, and hence be endemic to more geographically restricted, or patchy, habitat types.

Anecdotal evidence and the field knowledge of many entomologists support the hypothesis that insects tend to have smaller geographic ranges with different range midpoints than do other taxa, but more general data are scarce. Some evidence exists that the average range sizes of insect taxa are smaller than the average range sizes of vertebrates (Lees et al. 1999). Comparison of the minimum range sizes of insects and other taxa would depend on much finer scale data than are typically available. Studies such as Yeates et al. (2002) begin to address this deficiency. Yeates et al. (2002) found that both the absolute number of species and the percentage of species endemic to particular upland wet forests in northeast Australia were much higher for flightless insects than they were for vertebrates, an indication of the relative range sizes of the two groups (Yeates et al. 2002). Nine of the 14 uplands considered contained endemic wingless insects but no endemic vertebrates.

Work like that of Yeates et al. (2002) raises the question of whether the smallest viable geographic ranges of insects are generally smaller than those of vertebrates and, if so, how great the consequences of this trend for conservation will be. To the extent that minimum viable range sizes of species are a function of minimum viable population sizes, answers to these questions will depend on how tightly coupled body size and population density are at large scales and whether the relationship between the two variables is linear (e.g., Blackburn & Gaston 1997; Ackerman & Bellwood 2003). If we are serious about conserving insects, we need to obtain answers to these questions, even if for only a few well-studied taxa and regions.

Although many extinct, narrow-habitat specialists had historically small geographic ranges and low local abundances, this was not the case for all species. Several documented extinctions were of insect species with narrow habitat preferences in at least one life stage but with high local densities and often large geographic ranges. The Rocky Mountain locust (*Melanoplus spretus*) appears to be one such case. The Rocky Mountain locust was the single largest barrier to westward expansion in the United States in the 1800s. National programs were developed to "exterminate the locust" (Lockwood 1989). Lockwood and DeBrey (1990) plausibly argued that these efforts, combined with destruction of the floodplain habitats (by both extirpation of beavers and introduction of cattle) appear to have led to the locust's extinction. Although the locust's range stretched across the United States, its breeding grounds were a restricted habitat type and occupied a much smaller, patchier area. The last individual locust collected in 1902 is among just a handful of individuals preserved in museums. When the locust was abundant few apparently thought it was worthwhile to preserve specimens (Lockwood & DeBrey 1990).

Although the Rocky Mountain locust's combination of relatively narrow habitat specificity, large geographic range, and high abundance is not unique to insects, the force with which we attempted to extinguish the locust may now be. Although historical extinctions of vertebrates were often intentional (e.g., Bulte et al. 2003), modern extinctions of vertebrates rarely are. Humans appear to have intentionally extinguished a variety of insect species, including several species of Hawaiian moth (e.g., Howarth 1991). Most of these species appear to have been locally abundant but restricted in their habitat preference. Whereas such intentional extinctions are largely in the past for vertebrates, they may not be for insects. We are still willing to extirpate and even extinguish insects when they cause economic hardships. Pest species are exempt from the U.S. Endangered Species Act, so even if, for example, the Rocky Mountain locust were rediscovered it would probably be extinguished. The combined forces of unintentional and intentional human disturbance may put even abundant insect species with narrow habitat specificity at more risk than vertebrate species with similar ranges and habitat requirements.

Cases in which we are intentionally attempting to extinguish abundant insects may be relatively rare, but cases where we, as biologists, turn a blind eye to the consequences of our actions for abundant insect species abound. Such inaction is all but willful. Captive-bred animals (Windsor 1995; Gompper & Williams 1998; Perez & Palma 2001) and endangered plants (Lesica & Atthowe 2000) are often deloused or doused with pesticides without regard for the fate of their parasites. Such species are not intentionally being extinguished, but they are ignored in a way that increases their probability of extinction. Intentional introductions of biocontrol agents appear to have led to the local, if not global, extinction of a variety of insects. Eighty percent of the larvae of three native Saturniid moths in New England (U.S.A.) are infected with parasitic flies introduced as biocontrol agents, with negative effects on the populations of the Saturniids and their native parasites, many of which are missing (Boettner et al. 2000). Similar stories are also being revealed in Hawaii (e.g., Henneman & Memmott 2001). Amazingly, in many places, including the United States, the effects of insects introduced for biocontrol on other insects do not need to be tested (e.g., Boettner et al. 2001).

Extinctions of relatively abundant species with narrow habitat specificities make up a relatively large percentage

of documented insect extinctions (roughly 1 in 10, depending on how one defines *abundant*). Extinctions of such abundant species are probably overrepresented in lists of extinct insect species simply because we were more likely to have noticed that they went extinct. This says something about how we value insects. Extinctions of abundant insect species are perhaps not surprising because of the low value people in Western societies give insects (e.g., Kellert 1993). If the only reason we conserve species is for aesthetic and cultural values, perhaps ignoring insects is a logical way to allocate conservation dollars. However, if we really conserve species for the reasons we tend to list when we give talks and write textbooks (ecological functions, potential uses, and inherent values of species; reviewed for insects in Kellert 1993), we would be hard pressed to value a locust less than a condor or a tiger.

Coextinction

Because most insect species are parasites, the most restricted habitat occupied by many insects is arguably their host. Stork and Lyal (1993) highlighted the possibility that many parasites may go extinct when their hosts go extinct, a process they termed coextinction. They used the example of two louse species thought to have gone extinct with the Passenger Pigeon (*Ectopistes migratorius*). For a time, both Passenger Pigeon lice were on the IUCN list as extinct, but both species have since turned up on living pigeons (Price et al. 2000; Dunn 2002), leaving us with no well-documented cases of the coextinction of a vertebrate parasite. Subsequent studies have been reluctant to declare species extinct in light of the possibility that they might persist on alternate hosts. At least nine bird lice are thought to have been host specific on bird species that are now extinct (Koh et al. 2004*a*). Similarly, a species of ferret louse, *Neotrichodectes* sp., and a species of protozoan may have gone extinct with the black-footed ferret (*Mustella nigripes*) either when ferret populations were reduced or when the ferrets were deloused during captive breeding (Gompper & Williams 1998). Neither the nine bird lice nor the black-footed ferret louse is listed as extinct or even threatened (IUCN 2002). These lice are some of the many species of animal parasites biologists suspect may have gone extinct but have been reluctant to dismiss. The most endangered feline in the world, the Iberian lynx (*Lynx pardinus*), appears to be the sole host of the most endangered feline louse (Perez & Palma 2001), but this is just one of what are probably thousands of such cases.

The only well-documented case of extinction of an insect with a change in the abundance of its animal host (albeit a local rather than global extinction) is that of the large blue butterfly (*Maculinea arion*). As larvae, large blue butterflies are fed by workers and prey on larvae of a single species of host ant, *Myrmica sabuleti*. Biocontrol of introduced rabbits (*Oryctogalus cuniculus*) in the United Kingdom with *Myxoma* virus appears to have reduced the occurrence of open habitats, which the rabbit grazed. The host ant decreased in abundance as the amount of open habitat decreased, which in turn appears to have led to the extinction of the large blue (e.g., Elmes & Thomas 1992). Whether the extinction of the large blue led in turn to the extinction of any parasites the butterfly might have had remains undocumented. The example of the large blue serves to demonstrate potential extinction cascades and that parasites can go extinct even if their hosts simply decline in abundance.

Defined broadly, parasites also include herbivores, and a few cases of parasite extinction have been documented for host-specific plant feeders such as some butterflies and moths. When the chestnut blight attacked chestnuts (*Castanea dentata* Marsh.) and reduced them to thousands of fruitless wisps, Opler (1978) speculated that seven species of Lepidoptera might have been lost. Four of those species were subsequently found (P. Opler and D. Wagner, personal communication), but three species remain missing and are presumed extinct (IUCN 2002). Host-specific beetles, parasitoids, and other groups may have also been lost with the chestnut decline, but this remains to be investigated. More recently, Koh et al. (2004*a*) suggested that coextinction cause by the loss of host plants accounts for many of the regional extinctions of butterflies from Singapore.

Although few examples of coextinction have been documented, the mathematics of the process is straightforward. If one knows the average number of parasite species restricted to a single host species in a given taxon, then one can predict the number of host-specific parasites expected to have gone extinct per host (Koh et al. 2004*b*). Parasites dependent on two or more species in their most host-specific life stage are statistically more vouchsafed against extinction than more host-specific species but are nonetheless still at risk (Koh et al. 2004*b*). Recently, Koh et al. (2004*b*) used host specificity distributions for selected affiliate taxa (a general term including both parasites and mutualists) to estimate the number of historical extinctions due to coextinction, and the number of species likely to go extinct through coextinction were all endangered vertebrates and plants. They found that no fewer than 5000 insect species are likely to be endangered because of the endangerment of their hosts, and that no fewer than 100 species of beetles, lice, and butterflies alone are likely to have gone extinct because of the extinction of their hosts during the last 200 years.

The Koh et al. (2004*b*) estimates of coextinction rates take into account only extinctions likely to occur when hosts go extinct globally. Parasite and mutualist extinctions can also occur even if host species do not become extinct globally but are simply reduced in abundance and brought into captive breeding or seed bank programs and

stripped of their parasites. Given the large number of taxa recommended for captive breeding programs (e.g., 34% of the 3550 species considered by Seal et al. 1993), the losses from captive breeding alone could be hundreds of species. The potential magnitude of coextinctions should make them a key focus of conservation biology, yet the process of coextinction has been little studied (Koh et al. 2004*b*). Windsor (1995) listed the many reasons parasites deserve more attention from conservation biologists in an article entitled "Equal Rights for Parasites." These pleas seem to have been ignored. For example, I was able to find only two articles on lice in *Conservation Biology*, *Biological Conservation*, or *Biodiversity and Conservation* in the last 10 years, despite the fact that endangered bird and mammal parasites, such as lice, almost certainly outnumber endangered birds and mammals. Even if we persist in ignoring the conservation of parasites, it still behooves us to document parasite extinctions where and when we can. We need to understand parasite extinctions if only because of their likely high frequency.

Conclusions

A consideration of what we know about insect extinction seems to hold a number of lessons worth bearing in mind. First, although we know a fair amount about the modern extinctions of vertebrates, we know little about those of insects. This is not surprising, but it is worth reiterating because insects will almost inevitably represent most extinctions in the coming years. Second, although we estimate that most extinctions have been of insects, we have documented only a minority of insect extinctions. Finally, those extinctions we know something about seem to indicate we may be losing many insect species in ways that are not considered when conserving other taxa. I have considered two forms of extinction that may be more common in insects than in other taxa (extinction of narrow habitat specialists and coextinction), but insect extinctions may also differ in other important ways. For example, social insects appear to be disproportionately susceptible to extinction because of their small effective population sizes (Chapman & Bourke 2001), but sociality in vertebrates seems unlikely to account for much of the variation in extinction risk.

Documented insect extinctions hardly form a good data set from which to extrapolate and they may not be a random subset of all extinctions (they are most certainly not in their taxonomic focus), but if these trends are representative they are troubling. We need to focus more funding and research on conserving insects, but we also need to record the extinction of insects. Our greatest loss in terms of number of species is likely to be through the loss of insects. Our greatest loss of evolutionary history is likely to be through the loss of insects, or invertebrates more generally. Without rekindling the old debate about whether small or large species run the world, it is safe to say that most ecological processes are at least partially mediated by insects. Thus, losses of ecosystem function due to the losses of insect species will arguably be potentially great.

The key to understanding insect extinction is better documentation of the process itself. Documenting insect extinction serves the dual role of educating scientists about extinctions and providing concrete examples to the public of what we are doing. How might we better document insect extinctions? One pictures a thousand biologists running through the forests and savannas searching for their favorite species. Such time in the field will undoubtedly turn up some missing species, but more directed searches might prove more fruitful. In particular, regions with historical inventories should continue to be repeatedly inventoried, a task that would prove easier given persistent funding for parataxonomists (Goldstein 2004). Scouring skins of extinct vertebrates may permit discovery of many extinct invertebrates. Because we have no clear examples of coextinction of invertebrates from animal hosts, such examples would be of uncommon importance. If known extinct insects are at all representative, restricted habitats such as sand plains are also important places to search for species collected historically but perhaps not known from recent collections.

Conservation measures taken for vertebrates and those needed for insects (or invertebrates more generally) are not always the same. Species with endangered hosts may often be conserved by conserving the host, but not if pesticides continue to be used on rare plants and vertebrates (Lesica & Atthowe 2000). However, species with habitat types too small to have endemic plants or vertebrates are unlikely to find much in the way of conservation monies. If we are serious about conserving species diversity and not just charismatic species diversity, conserving a few key and tiny habitat types such as the Antioch Dunes is likely to save more species than will the millions of dollars spent on vertebrate umbrella species. If we are losing many hundreds of species from tiny, ignored habitats, our relative disinterest in the conservation of these habitats is a measure of how little we really value insects and their conservation. We can decide to value insects much less than vertebrates and plants, but we should make this decision consciously and not through neglect.

Acknowledgments

I especially thank D. Wagner and C. Labandiera who coorganized the insect extinction symposium at the Entomological Society of America meetings that provided an impetus for this work. D. Wagner, J. Powell, D. Polhemus, R. K. Colwell, M. Wall, J. Leibherr, J. Caira, S. Spector, N. Stork, M. Gavin, B. P. Miller, A. Latimer, J. M. Morales, G. Boettner, K. Brennan, and K. Jensen all contributed valuable insights to this essay.

Literature Cited

Ackerman, J. L., and D. R. Bellwood. 2003. The contribution of small individuals to density-body size relationships. Oecologia **136:**137–140.

Blackburn, T. M., and K. J. Gaston. 1997. A critical assessment of the form of the interspecific relationship between abundance and body size in animals. Journal of Animal Ecology **66:**233–249.

Boettner, G. H., J. S. Elkinton, and C. J. Boettner. 2000. Effects of a biological control introduction on three nontarget native species of Saturniid moths. Conservation Biology **14:**1798–1806.

Bulte, E. H., R. D. Horan, and J. F. Shogren. 2003. Is the Tasmanian tiger extinct? A biological-economic re-evaluation. Ecological Economics **45:**271–279.

Chapman, R. E., and A. F. G. Bourke. 2001. The influence of sociality on the conservation biology of social insects. Ecology Letters **4:**650–662.

Dunn, R. R. 2002. On parasites lost. Wild Earth Spring **12:**13–15.

Elmes, G. W., and J. A. Thomas. 1992. Complexity of species conservation in managed habitats—interaction between *Maculinea* butterflies and their ant hosts. Biodiversity and Conservation **1:**155–169.

Goldstein, P. Z. 2004. Systematic collection data in North American invertebrate conservation and monitoring programs. Journal of Applied Ecology **41:**175–181.

Gompper, M. E., and E. S. Williams. 1998. Parasite conservation and the black-footed ferret recovery program. Conservation Biology **12:**730–732.

Henneman, M. L., and J. Memmott. 2001. Infiltration of a Hawaiian community by introduced biological control agents. Science **293:**1314–1316.

Howarth, F. G. 1991. Environmental impacts of classical biological control. Annual Review of Entomology **36:**485–509.

IUCN (World Conservation Union). 2002. Red list of threatened species. IUCN, Gland, Switzerland. Available from http://www.redlist.org (accessed June 2004).

Kellert, S. R. 1993. Values and perceptions of invertebrates. Conservation Biology. **7:**845–855.

Koh, L. P., N. S. Sodhi, and B. W. Brook. 2004*a*. Co-extinctions of tropical butterflies and their hostplants. Biotropica **36:**272–276.

Koh, L. P., R. R. Dunn, N. S. Sodhi, R. K. Colwell, H. C. Proctor, and V. S. Smith. 2004*b*. Species coextinctions and the biodiversity crisis. Science **305:**1632–1634.

Lees, D. C., C. Kremen, and L. Andriamampianina. 1999. A null model for species richness gradients: bounded range overlap of butterflies and other rainforest endemics in Madagascar. Biological Journal of the Linnean Society **67:**529–584.

Lesica, P., and H. E. Atthowe. 2000. Should we use pesticides to conserve rare plants? Conservation Biology **14:**1549–1550.

Liebherr, J. K., and D. A. Polhemis. 1997. Comparisons to the century before: the legacy of R. C. L. Perkins and Fauna Hawaiiensis as the basis for a long-term ecological monitoring program. Pacific Science 490–504.

Lockwood, J. A. 1989. Taxonomic status of the Rocky Mountain Locust: morphometric comparisons of *Melanoplus spretus* (Walsh) with solitary and migratory *Melanoplus sanguinipes* (F.). Canadian Entomologist **121:**1103–1109.

Lockwood, J. A., and L. D. DeBrey. 1990. A solution for the sudden and unexplained extinction of the Rocky Mountain grasshopper (Orthoptera: Acrididae). Environmental Entomology **19:**1194–1205.

Manne L. L., T. M. Brooks, and S. L. Pimm. 1999. Relative risk of extinction of passerine birds on continents and islands. Nature **399:**258–261.

Mattoni, R., R. Longcore, and V. Novotny. 2000. Environmental auditing. Arthropod monitoring for fine-scale habitat analysis: a case study of the El Segundo sand dunes. Environmental Management **25:**445–452.

Mawdsley, N. A., and N. E. Stork. 1995. Species extinctions in insects: ecological and biogeographical considerations. Pages 321–369 in R. Harrington and N. E. Stork, editors. *Insects in a changing environment*. Academic Press, London.

McCafferty, W. P. 2001. Status of some historically unfamiliar American mayflies (Ephemeroptera). Pan-Pacific Entomologist **77:**210–218.

McKinney, M. L. 1999. High rates of extinction and threat in poorly studied taxa. Conservation Biology **13:**1273–1281.

Opler, P. A. 1978. Insects of American chestnut: possible importance and conservation concern. Pages 83–85 in J. McDonald, editor. The American chestnut symposium. West Virginia University Press, Morgantown.

Pearson, D. L., and F. Cassola. 1992. World-wide species richness patterns of tiger beetles (Coleoptera: Cicindelidae): indicator taxon for biodiversity and conservation studies. Conservation Biology **6:**376–391.

Perez, J. M., and R. L. Palma. 2001. A new species of *Felicola* (Phthiraptera: Trichodectidae) from the endangered Iberian lynx: another reason to ensure its survival. Biodiversity and Conservation **10:**929–937.

Pimm, S. L., and P. Raven 2000. Biodiversity—extinction by numbers. Nature **403:**843–845.

Powell, J. A. 1978. Endangered habitats for insects: California coastal sand dunes. Atala **6:**41–55.

Price, R. D., D. H. Clayton, and R. J. Adams. 2000. Pigeon lice down under: taxonomy of Australian *Campanulotes* (Phthiraptera: Philopteridae), with a description of *C. durdeni n.* sp. Journal of Parasitology **86:** 948–950.

Priddel, D., N. Carlile, M. Humphrey, S. Fellenberg, and D. Hiscox. 2003. Rediscovery of the "extinct" Lord Howe Island stick-insect (*Dryococelus australis* (Montrouzier))(Phasmatodea) and recommendations for its conservation. Biodiversity and Conservation **12:**1391–1403.

Redak, R. A. 2000. Arthropods and multispecies habitat conservation plans: are we missing something? Environmental Management **265:**97–107.

Rentz, D. C. F. 1977. A new and apparently extinct katydid from Antioch sand dunes. Entomological News **88:**241–245.

Seal, U. S., S. A. Ellis, T. J. Foose, and A. P. Byers. 1993. Conservation assessment and management plans (CAMPs) and global action plans (GAPs). Captive Breeding Specialists Group Newsletter **4:**5–10.

Seow-Choen, F. 1997. Stick and leaf insect (Phasmida: Insecta) biodiversity in the nature reserves of Singapore. Proceedings of the Nature Reserves Survey Seminar. Gardens' Bulletin Singapore. **49:**297–312.

Snyder, N. F. R., S. R. Derrickson, S. R. Beissinger, J. W. Wiley, T. B. Smith, W. D. Toone, and B. Miller. 1996. Limitations of captive breeding in endangered species recovery. Conservation Biology **10:**338–348.

Stork, N. E. 1997. Measuring global biodiversity and its decline. Pages 41–68 in J. H. Press, editor. Biodiversity II. Joseph Henry Press, Washington, D.C.

Stork, N. E., and C. H. C. Lyal. 1993. Extinction or "co-extinction" rates? Nature **366:**307.

Thomas, C. D., et al. 2004. Extinction risk from climate change. Nature **427:**145–148.

USFWS (U.S. Fish & Wildlife Service). 2001. Antioch Dunes National Wildlife Refuge draft comprehensive conservation plan and environmental assessment. USFWS, Washington, D.C.

Windsor, D. 1995. Equal rights for parasites. Conservation Biology **9:** 1–2.

Yeates, D. K., P. Bouchard, and G. B. Monteith. 2002. Patterns and levels of endemism in the Australian west tropics rainforest: evidence from flightless insects. Invertebrate Systematics **16:**605–619.

HYDROLOGICAL PROCESSES
Hydrol. Process. **20**, 3159–3178 (2006)
Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/hyp.6325

The potential roles of biological soil crusts in dryland hydrologic cycles

Jayne Belnap*
US Geological Survey, Southwest Biological Science Center, Canyonlands Research Station, 2290 S. West Resource Blvd., Moab, UT 84532, USA

Abstract:

Biological soil crusts (BSCs) are the dominant living cover in many drylands of the world. They possess many features that can influence different aspects of local hydrologic cycles, including soil porosity, absorptivity, roughness, aggregate stability, texture, pore formation, and water retention. The influence of biological soil crusts on these factors depends on their internal and external structure, which varies with climate, soil, and disturbance history. This paper presents the different types of biological soil crusts, discusses how crust type likely influences various aspects of the hydrologic cycle, and reviews what is known and not known about the influence of biological crusts on sediment production and water infiltration versus runoff in various drylands around the world. Most studies examining the effect of biological soil crusts on local hydrology are done by comparing undisturbed sites with those recently disturbed by the researchers. Unfortunately, this greatly complicates interpretation of the results. Applied disturbances alter many soil features such as soil texture, roughness, aggregate stability, physical crusting, porosity, and bulk density in ways that would not necessarily be the same if crusts were not naturally present. Combined, these studies show little agreement on how biological crusts affect water infiltration or runoff. However, when studies are separated by biological crust type and utilize naturally occurring differences among these types, results indicate that biological crusts in hyperarid regions reduce infiltration and increase runoff, have mixed effects in arid regions, and increase infiltration and reduce runoff in semiarid cool and cold drylands. However, more studies are needed before broad generalizations can be made on how biological crusts affect infiltration and runoff. We especially need studies that control for sub-surface soil features such as bulk density, micro- and macropores, and biological crust structure. Unlike the mixed effects of biological crusts on infiltration and runoff among regions, almost all studies show that biological crusts reduce sediment production, regardless of crust or dryland type. Published in 2006 by John Wiley & Sons, Ltd.

KEY WORDS arid; desert; infiltration; microbiotic crusts; runoff; semiarid; water cycles; water erosion

Received 1 April 2005; Accepted 4 August 2005

INTRODUCTION

It is well known that many soil factors influence local hydrologic regimes. The most often discussed variables controlling the dynamics of sediment production and runoff versus infiltration include factors such as soil texture, degree of soil aggregation, soil structure, plant and plant litter cover, rock cover, and physical crusting. Less understood and discussed is how the presence of biological soil crust (BSC) communities (consisting of soil surface-dwelling cyanobacteria, green algae, microfungi, bacteria, lichens, and bryophytes) influences local hydrologic dynamics. BSCs can profoundly influence many soil surface characteristics known to affect local hydrologic patterns (reviewed in Warren, 2003a,b), including soil texture, aggregation, cohesiveness, absorptivity, roughness, cracking, micro- and macropore formation, water retention, and patterns of infiltration, as well as the composition and architectural structure of vascular plant communities. Little is known about the relative importance of these features among themselves or relative to sub-surface soil characteristics, as

* Correspondence to: Jayne Belnap, US Geological Survey, Southwest Biological Science Center, Canyonlands Research Station, 2290 S. West Resource Blvd., Moab, UT 84532, USA. E-mail: jayne_belnap@usgs.gov

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few experiments have utilized the same equipment, measured the same variables across sites, or successfully distinguished the influence of crusts from other site variables.

This paper reviews what is known about how biological crusts influence soil surface features and local hydrologic processes and presents a conceptual model for how the modification of soil surface features likely influences local hydrologic patterns. It is hoped that this discussion and the conceptual framework presented will provide structure and stimulus for a more systematic investigation into how biological crusts affect local hydrologic cycles.

AN OVERVIEW OF BIOLOGICAL SOIL CRUSTS

Biological soil crusts are created by an intimate association between soil particles and cyanobacteria, green algae, microfungi, bacteria, lichens, and bryophytes which live within, or immediately on top of, the uppermost millimetres of soil (Belnap and Gardner, 1993). These organisms, and the extracellular polysaccharide materials associated with them, connect soil particles together, creating a coherent living crust that covers the surface of many dryland regions. Biological soil crusts have had many names, including cryptogamic, cryptobiotic, microbiotic, and microphytic soil crusts.

Distribution of biological soil crusts

Biological soil crusts organisms have a very wide distribution. They occur on most soil types and in almost all vegetative communities where sunlight can reach the soil surface. They have low moisture requirements and a high tolerance of extreme temperatures and light, thus enabling them to survive under conditions that limit vascular plant growth (Belnap *et al*., 2003a). Because of these traits, they are often the dominant ground cover in low-productivity environments such as hyperarid, arid, semiarid, sub-humid, alpine, and polar regions, which constitute over 40% of the world's terrestrial land mass (Figure 1). Biological crusts also occur in localized areas in more mesic regions (e.g. pine barrens, serpentine soils, temperate steppe). Only the tropical evergreen rain forests appear to lack BSCs (Büdel and Lange, 2003).

Soils in dryland regions generally have a pH of 7 or greater. This factor, combined with the relatively high potential evapotranspiration (PET) found in these areas, results in the soil surface being mostly dominated by cyanobacteria, lichens, and mosses. Under these conditions, the biomass and cover of green algae, microfungi, and other bryophytes (e.g. liverworts) are quite limited. For this reason, we will only discuss cyanobacteria, lichens, and mosses in the following review. However, when considering the influence of biological crusts on hydrologic processes, the function of green algae and microfungi is similar to cyanobacteria, and the function of other bryophytes is similar to lichens, such as liverworts. Thus, it is not expected that the fundamental principles discussed below will show much change if the more common dryland species are replaced by those found in relatively more mesic areas.

Types of biological soil crusts among climatic regions

The appearance, biomass, and species composition of BSCs vary widely among climatic regimes. These differences in external and internal structure result in distinct crust types, with each type having a different effect on ecological and hydrologic processes. Multiple classification schemes for crust types have been proposed (reviewed in Belnap *et al*., 2003a). The classification system presented here is based on factors that influence runoff, infiltration, and sediment production and is therefore helpful in discussing how crusts may affect hydrologic function. This system defines four types of biological crust (Figure 2).

Smooth crusts occur in hyperarid hot drylands (e.g. Atacama, Sahara deserts) where soils never freeze and where PET is very high (Figure 2). The crust biota in smooth crusts is dominated by a thin layer of cyanobacteria and fungi that live on or just below the soil surface, with rare pockets of lichens and mosses in specialized microhabitats. Soils are generally young, coarse, and relatively unweathered. When the individual

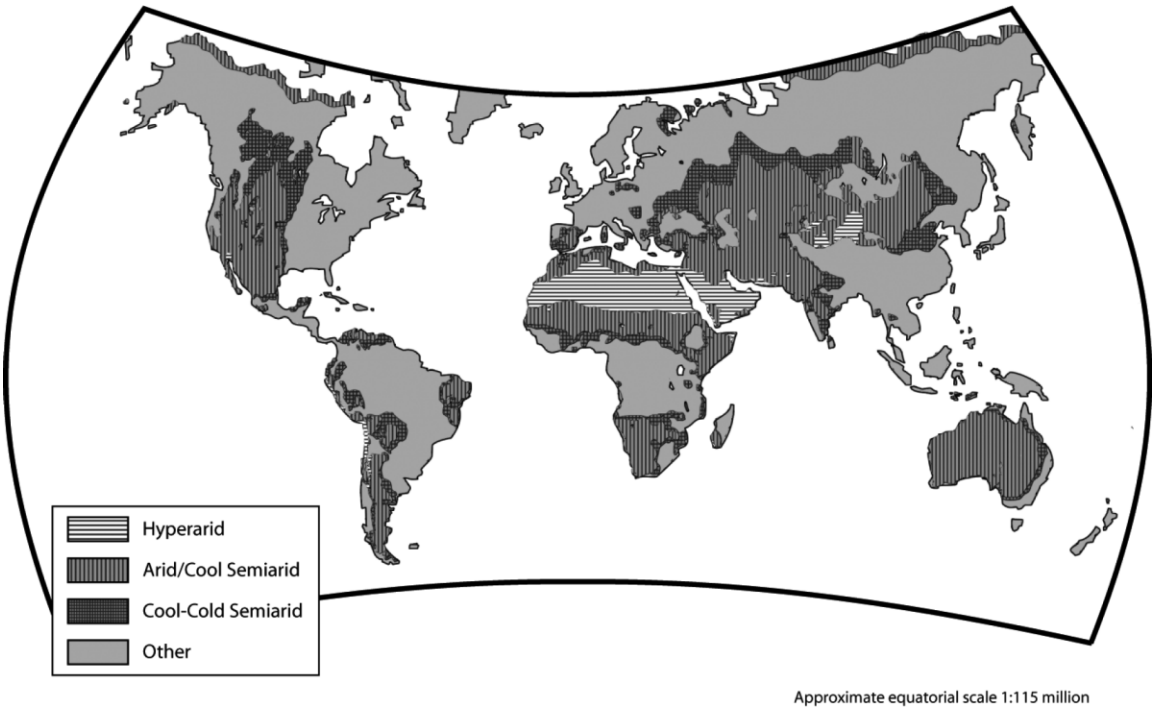

Figure 1. Patterned areas represent regions where biological soil crusts are likely to influence local hydrologic processes. Cumulatively, these lands represent 40% of the Earth's terrestrial surface

soil particles are bound together by the crust biota, the smoothness of the soil surface is increased. Very low moisture availability results in a low biomass and thus low absorptivity of crust organisms, with relatively high soil surface porosity and low surface roughness.

Rugose crusts occur in dryland regions where soils do not freeze, but with lower PET than hyperarid deserts (e.g. low-elevation Sonoran, Mojave, Australian deserts; Figure 2). Rugose crusts are dominated by a thin layer of cyanobacteria and fungi. In drier regions of these deserts, they contain sparse patches of lichens and mosses growing on the relatively even soil surface. As moisture increases within these regions, lichen and moss cover increases as well, although the soil surface still remains fairly flat. Overall low moisture results in moderately low crust biomass, soil surface roughness, and crust absorptivity, whereas soil surface porosity is moderately high.

Pinnacled crusts occur in mid-latitude cool desert regions (e.g. low-elevation Colorado Plateau, mid-latitude China deserts, high-elevation Sonoran and Mojave deserts) where soils freeze and PET is lower than in hot deserts (Figure 2). Pinnacled crusts are dominated by relatively thick layers of cyanobacteria with up to 40% lichen and moss cover. This crust type is characterized by strikingly pedicelled mounds formed as soils uplifted by frost heaving are differentially eroded by downward-cutting water. These castle-like mounds can be up to 15 cm high, with thin tips 4–10 mm across. Crust biomass, crust absorptivity, and soil surface roughness are high in this crust type, with relatively low soil surface porosity.

Rolling crusts occur in colder, lower PET regions (e.g. northern Great Basin, high-latitude deserts) than pinnacled crusts (Figure 2). Lichens and mosses heavily dominate these thick crusts. The upward frost heaving of the soil is counteracted by a cohesive, thickly encrusted mat of lichens and mosses. This mat presents an erosion-resistant surface that prevents differential downward cutting, creating a roughened, slightly rolling crust surface. The low PET in these regions allows for very high crust biomass and surface absorptivity, with low soil surface porosity and moderate soil surface roughness.

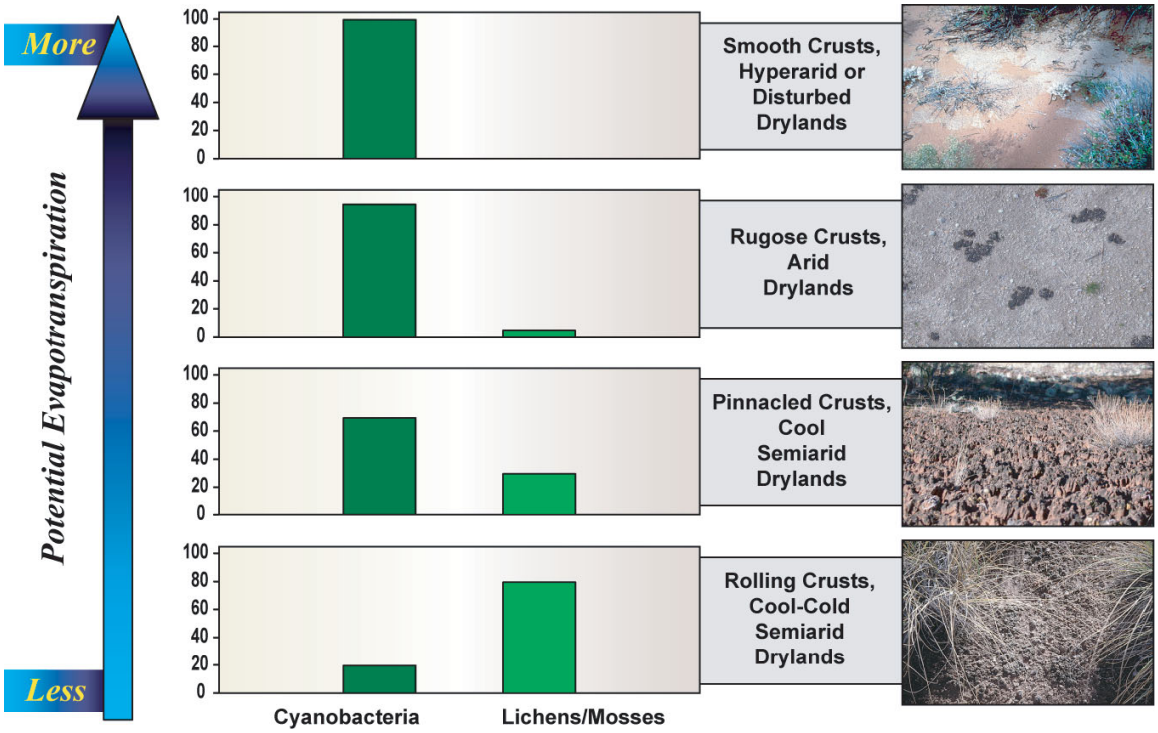

Figure 2. Classification of biological crust types based on flora and external morphology. The flora of BSCs change with rainfall timing and amount. In hyperarid deserts, biological crusts are dominated by cyanobacteria, whereas in dryland regions with lower PET, they are dominated by lichens and mosses. The external morphology of biological crusts also changes with climate. In hyperarid regions, biological crusts are flat. Decreasing PET and freezing soils increase the surface roughness of crusts

Types of biological soil crusts within a given climatic region

Within a given climatic zone, many factors can influence the external morphology of BSCs. Crusts with similar species and biomass are flatter when they occur on clay and silty soils compared to those on adjacent coarser soils. In soils with weak crystalline structures (e.g. soils derived from calcite and gypsum), extracellular polysaccharide materials combine with the dissolved minerals when soils are wet to create very strong microbial sheaths that are part organic and part inorganic materials. The internal strength of these soils resists winter frost heaving, and they do not form the highly dissected surfaces that may be found in adjacent sandy soils. Cyanobacteria generally dominate soils that are very sandy (>90%), very salty, or have a high content of shrink-swell clays, regardless of the climatic zone. Lichen cover generally increases with an increase in the amount of carbonate, gypsum, and/or silt in the soil (Büdel and Lange, 2003).

In soils with heavy physical crusting, the surface morphology of crusts is primarily controlled by soil physical and chemical characteristics, and the biological components have only a limited effect. If only cyanobacteria are present under these circumstances, the resultant crusts are smooth. If lichens and mosses colonize as well, the slight roughening of the soil surface creates a rugose or rolling crust. Pinnacled crusts seldom form in soils with a high degree of physical crusting.

Internal structure of biological soil crusts

The internal structure of soil crusts varies with the crust flora. Cyanobacteria and fungi, ubiquitous to all crust types, provide most of the cohesive quality of the BSCs. Bare soils are first colonized by large, mobile filamentous cyanobacteria (e.g. *Microcoleus vaginatus*; Figures 3(a), 4) that live 1–4 mm below the soil

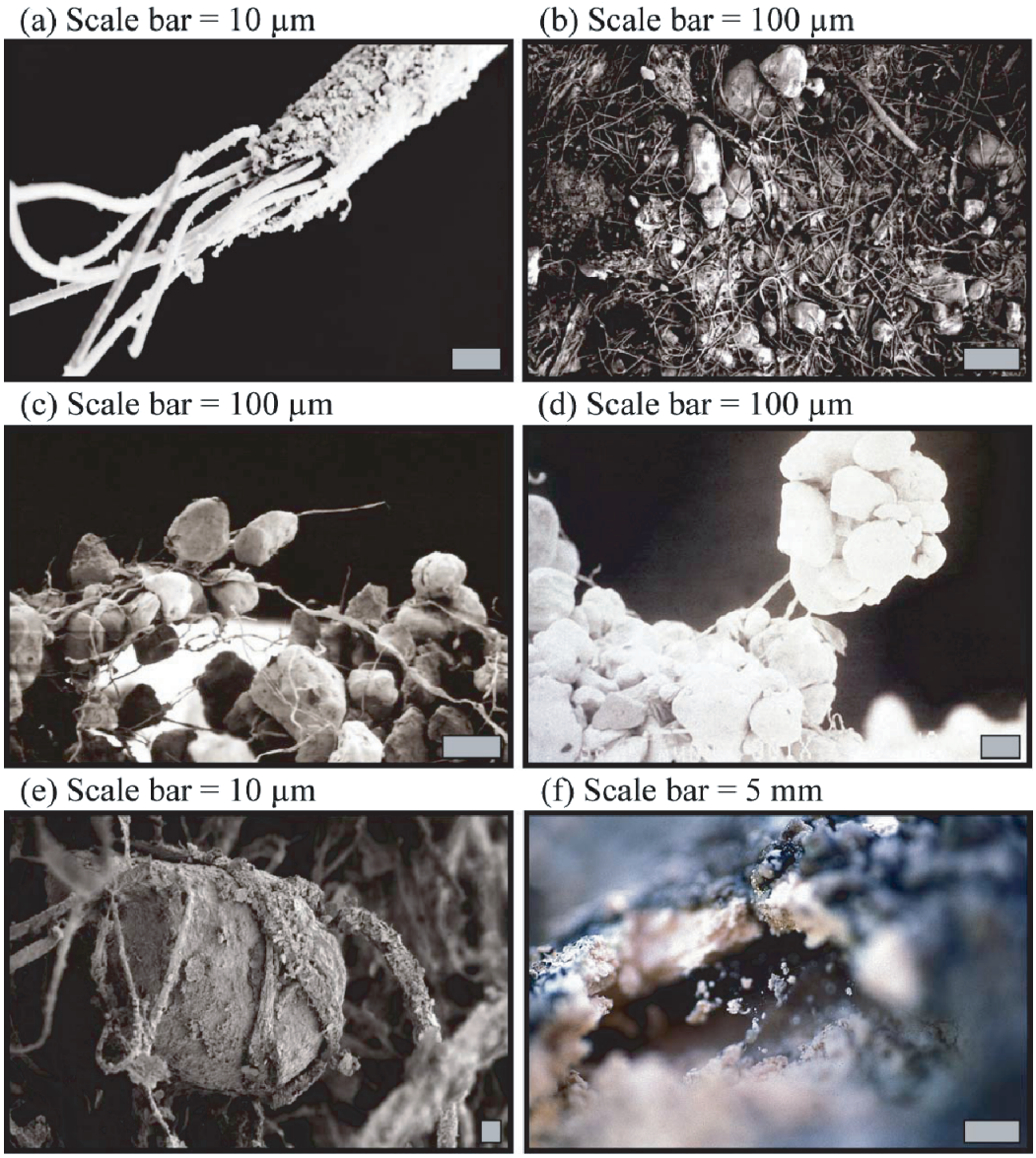

Figure 3. (a) *Microcoleus vaginatus* in sandy soils (bar = 10 μm). (b) When wetted (using freeze substitution), sheaths and filaments swell and cover the soil surface (bar = 100 μm). (c) Sheaths adhere firmly to the sand grain surfaces, binding the grains together (bar = 100 μm). (d) Soil aggregate formed by cyanobacterial sheaths (bar = 100 μm). (e) Multiple sheaths wrap around a sand grain, holding it firmly in place (bar = 10 μm). (f) Cyanobacterial sheaths hold together multiple soil aggregates (bar = 5 mm). Images (a) through (e) are scanning electron micrographs of BSCs. Image (f) is a photograph

surface. However, during wet periods, they can cover the soil surface (Figure 3(b)). Later, smaller and less mobile cyanobacteria colonize (e.g. *Nostoc, Scytonema*). These smaller species live on or just below the soil surface, creating layers of species in the soils (Garcia-Pichel and Belnap, 1996; Belnap, 2003a). The sticky, polysaccharide outer sheaths of the cyanobacteria wind throughout the uppermost soil layers (Figure 3(c)), linking soil particles together, forming soil aggregates (Figure 3(d)). These aggregates themselves are then further linked together by cyanobacterial strands (Figure 3(e), (f)).

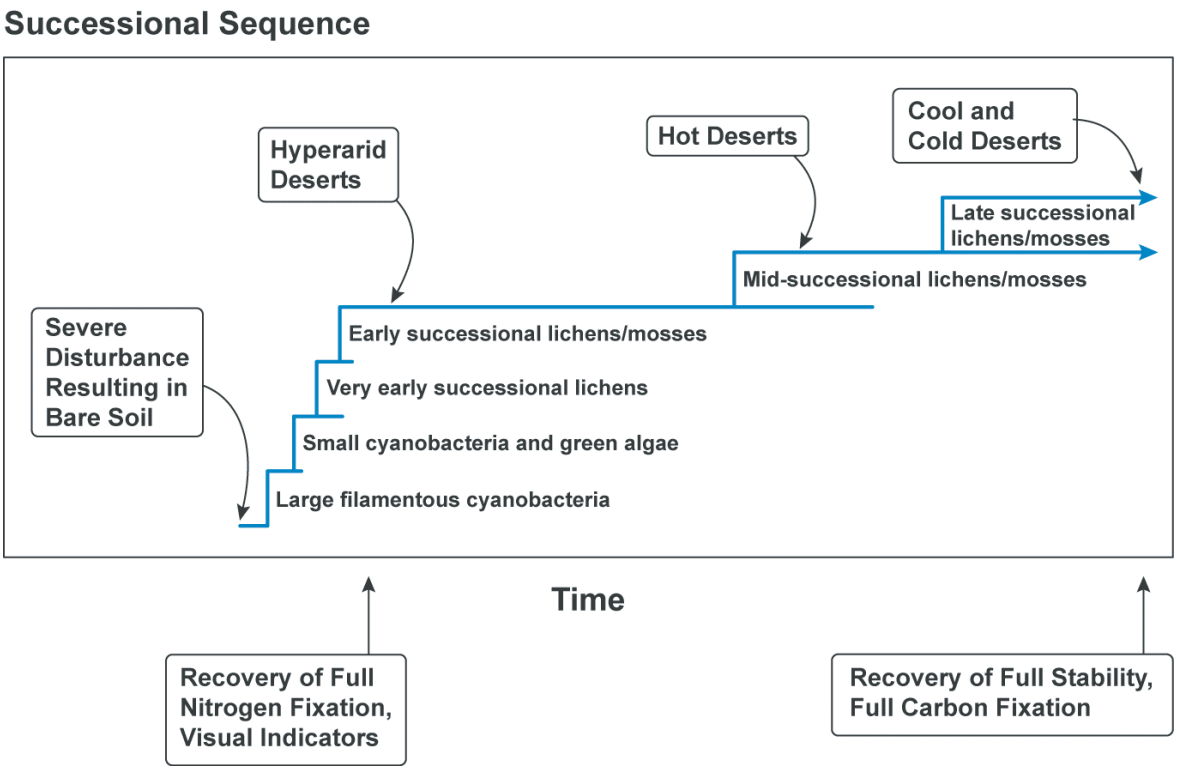

Figure 4. Colonization sequence for biological crust species. Arrows indicate colonization events; the length of the line indicates relative recovery time for each successional group. Species indicative of large filamentous cyanobacteria are *Microcoleus* spp.; for small cyanobacteria, *Nostoc* spp. and *Scytonema* spp.; very early successional lichens, *Collema* spp.; early successional lichens and mosses, *Placidium* spp. and *Pterygoneurum* spp.; mid successional lichens and mosses, *Psora* spp., *Fulgensia* spp., *Bryum* spp.; late successional lichens and mosses, *Acarospora* spp., *Panneria* spp

Once the soil surface is stabilized by cyanobacteria, lichens and mosses colonize if climate conditions permit (Figure 4). Unlike the soil cyanobacteria, which grow within the soil, lichens and bryophytes have most of their biomass above the soil surface (Figure 5), which protects underlying soils from raindrop impact and resists detachment of particles during overland flow events. Lichens and bryophytes also have anchoring structures (rhizoptae, rhizinae, and rhizomorphs; Poelt and Baumgärtner, 1964; Sanders, 1994) that penetrate down into the soil as deep as 14 mm (Belnap *et al*., 2003a). In addition, multi-branched, subterranean moss protonemata are interspersed throughout the soil crust matrix. Combined, these structures form a dense, subterranean network of tissue that is intimately connected with soil particles and that strongly contributes to soil stability (Belnap and Gardner, 1993; Belnap, 2003a).

Effects of disturbance and climate change on external morphology and internal structure of crusts

The intensity, type, and time since disturbance can control both the external and internal structure of biological soil crusts. Crustal components are brittle and easily crushed, especially when dry. Once buried, these photosynthetic organisms die. Damage to buried sheath material cannot be repaired, as living cyanobacteria are no longer present to secrete new sheath material. Most soil surface disturbances leave surfaces flattened relative to the previously roughened surface (Figure 2), and early re-colonization is exclusively by the large cyanobacterial species (Figures 3(a), 4). Recovery of both the external and internal structure of crusts occurs in the sequence outlined above, with the final developmental stage determined by climate (Figure 4). Biological soil crust organisms are also sensitive to other types of disturbance, including

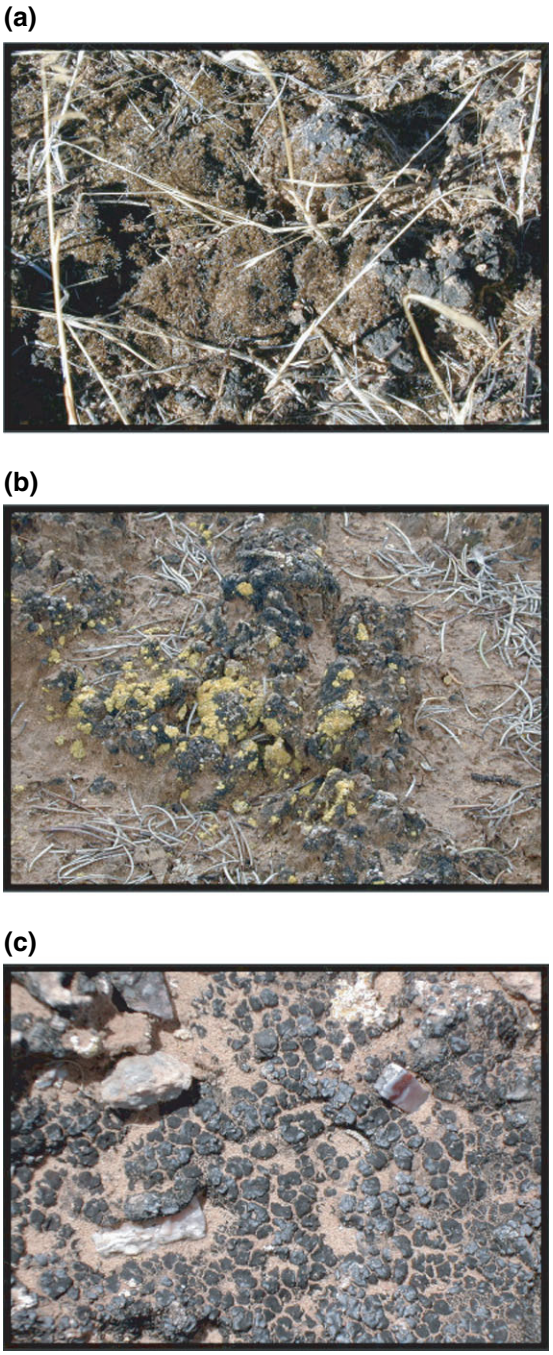

Figure 5. Photos of lichens and mosses on desert soil surfaces. Note that both lichens and mosses have substantial tissue above the surface that can completely cover soil pores. Cover can be continuous (a), discontinuously clumped (b), or more evenly, but still discontinuously (c) spread across the soil surface

air pollution, herbicides (Zaady *et al*., 2004; Belnap *et al*., 2003b), and climate change, including changes in precipitation (Belnap *et al*., 2004) and increased air temperatures (Belnap *et al*., 2006).

BIOLOGICAL CRUSTS CAN INFLUENCE HYDROLOGIC PROCESSES

Soil texture

Relatively unweathered, coarse-textured soils cover large amounts of global dryland surfaces. In these soils, particles deposited by aeolian processes can represent up to 60% of soil fines (Danin and Yaalon, 1982; Reynolds *et al*., 2001). Airborne silts and clays are trapped by sticky cyanobacterial sheaths, by surface roughness created by biological crusts, and by protruding moss stems and lichen thalli. This results in a thin layer of silt and clay on the soil surface that is often lacking where biological crusts are absent (Verrecchia *et al*., 1995). Silt and clay particles increase the absorptivity of the soil. However, they can also decrease soil porosity (Brady and Weil, 1996). It is predicted that dust-trapping efficiency will increase with increasing surface roughness, cyanobacterial biomass, and lichen-moss cover. Therefore, the dust-trapping ability of the soil surface is expected to increase in the following order: bare soil < smooth crust < rugose crust < pinnacled crust < rolling crust (Figure 6).

Absorptivity of biological crust organisms

All BSC biota absorb water, but to varying degrees. Cyanobacteria absorb up to 10 times their volume of water and 8–12 times their dry weight (Campbell, 1979; Verrecchia *et al*., 1995). Water absorption by lichens and mosses varies greatly among species. Gelatinous lichens and mosses can expand their cover and biomass by up to 13 times or more when wetted (Galun *et al*., 1982), whereas crustose and squamulose lichens absorb smaller amounts of water (Blum, 1973). Mosses can absorb water directly, trap water in specialized leaf structures, and differentially channel water to their stems with special leaf arrangements (Catcheside, 1980).

Crust types vary widely in their thickness. Smooth and rugose crusts tend to be thin, whereas pinnacled and rolling crusts are much thicker, with occasional polysaccharide sheath material or moss anchoring structures found up to 10 cm below the soil surface. Biomass also increases as PET decreases. Therefore, the degree to which biological crusts affect soil absorptivity will depend on crust features as controlled by climatic factors. Unfortunately, crust absorptivity has not been quantified in any systematic way for either individual species or crusts as a mixed community. However, because cyanobacteria, mosses, and lichens all absorb water, it is expected that an increase in biomass and cover of these organisms will increase absorptivity of the crusts. Thus, absorptivity of different soil surface types is expected to increase in the following order: bare soil < smooth crust < rugose crust < pinnacled crust < rolling crust (Figure 6).

Soil surface porosity and the formation of micro- and macropores

Biological crust organisms, by their very presence on the soil surface and by their ability to swell upon wetting, can clog soil pores and thus reduce soil porosity (Avnimelech and Nevo, 1964; Campbell, 1979; Eldridge and Greene, 1994; Verrecchia *et al*., 1995; Kidron *et al*., 1999). This is especially true when the crust organisms are concentrated on the soil surface (Figure 3(b)). However, cyanobacteria occur as strands, thus leaving spaces at the soil surface. Therefore, cyanobacteria are less likely to clog pores than lichens and mosses, which are large enough to cover soil pores completely (Figure 5(a)). However, the cover of any of these organisms is seldom continuous (Figure 5(b–c)). Because cyanobacteria occur on the soil surface, high intensity raindrop impact can break apart aggregates formed by the cyanobacterial filaments, allowing pores to clog (Faust, 1970). Unlike most cyanobacteria, lichen tissue and moss stems completely protect underlying soil aggregates. Data suggest that porosity at the soil surface decreases as cyanobacterial biomass and lichen/moss cover increase (Figure 6), especially once lichen and moss cover exceeds a critical threshold (Eldridge, 2003).

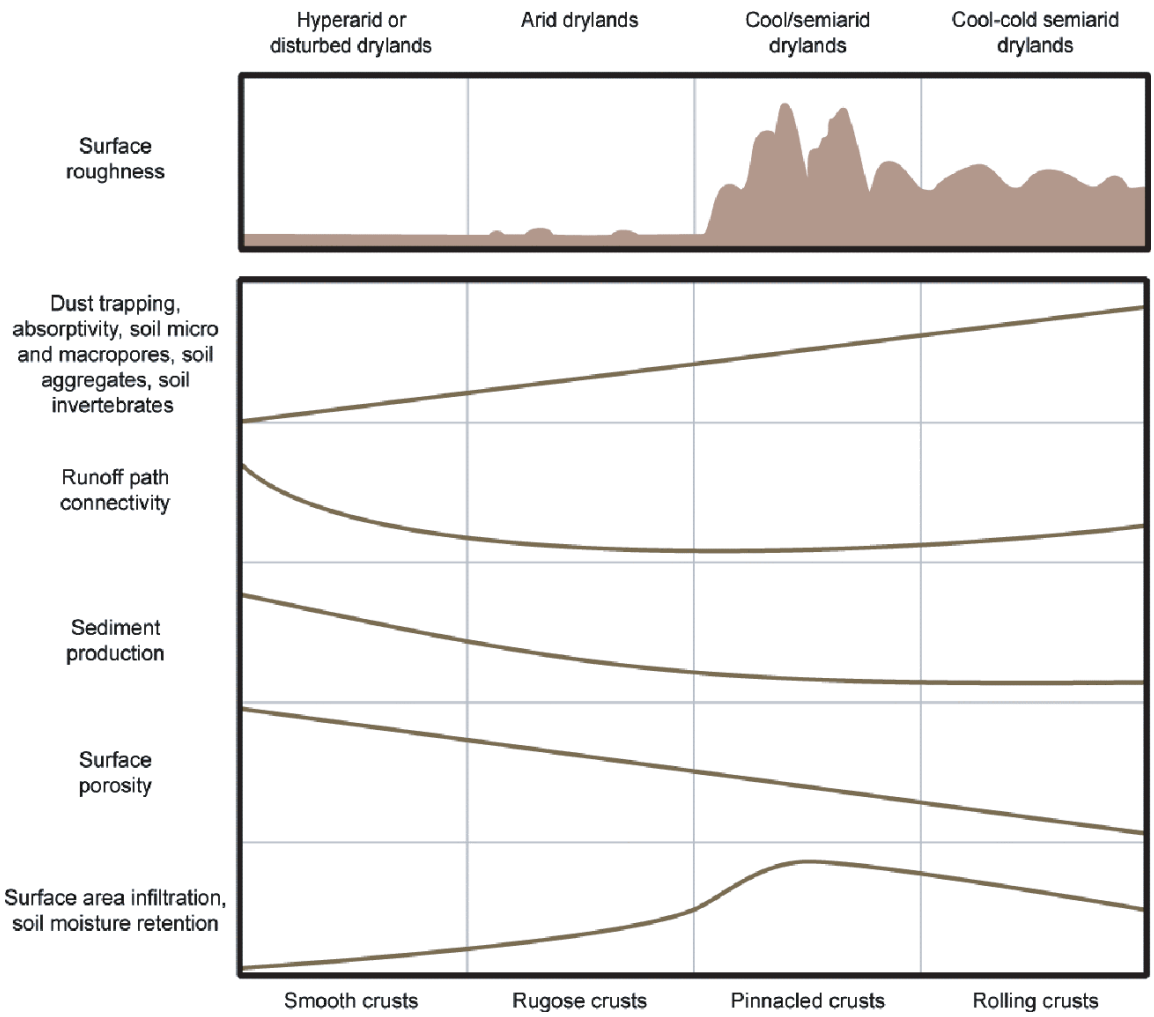

Figure 6. Conceptual diagram of the possible influence of different crust types on soil features that affect local hydrologic cycles

Counteracting the tendency to clog soil pores, biological crust organisms are known to increase aggregation via soil carbon additions. This creates micropore channels, which are known to increase water infiltration (Greene, 1992; Eldridge *et al*., 2001). These micropore channels are also stabilized by crust organisms when soils are exposed to rainfall or overland flow (McIntyre, 1958; Bond and Harris, 1964; Rogers, 1989; Eldridge *et al*., 2001; Eldridge, 2003). Therefore, as the numbers of cyanobacterial filaments and anchoring structures increase with decreasing PET and thus biological crust cover, the number of soil aggregates and micropores are expected to increase as well (Figure 6).

Soil micropores and macropores are also created by burrowing soil invertebrates, many of which feed on the cyanobacteria, lichens and mosses found in BSCs. These soil invertebrates include mites, collembolans, nematodes, rotifers, tardigrades, isopods, snails, mole crickets, tenebrionid beetles, protozoans, termites, and ants. Studies show that the diversity and abundance of soil invertebrates increase as lichen and moss cover increases (reviewed in Belnap, 2003b).

Because of larger numbers of filaments, lichen–moss anchoring structures, greater soil carbon, and burrowing invertebrates, an increase in micropore formation is expected with increased cyanobacterial biomass

and lichen/moss cover. Therefore, it is expected that pore formation on different soil surfaces will increase in the following order: bare soil < smooth crust < rugose crust < pinnacled crust < rolling crust (Figure 6). However, we have no reliable data on this. In addition, we have no data on the conditions under which pore clogging by crust organisms retards infiltration more or less than the formation and stabilization of pores increase infiltration.

Differential infiltration patterns

As discussed above, different soil biota can influence infiltration differently. Cyanobacteria generally occur just below the surface in strands with spaces between them (Figure 3(a)), while lichen and moss tissue can have low to high coverage of the soil surface (Figure 5(a–c)). Thus, water is expected to infiltrate more evenly in bare soil, a smooth cyanobacterial crust type, or in a continuous lichen–moss crust than in rugose and pinnacled crusts where lichens and mosses occur in patches. However, biomass within any crust type is also concentrated in patches, and differential infiltration patterns have been observed at a very small scale (e.g. Bond and Harris, 1964).

Soil surface roughness

The presence or lack of soil surface roughness can have a large influence on water retention times at a given site (Thurow, 1991). Smooth crusts flatten the soil surface and thus reduce water retention times relative to uncrusted surfaces (Yair, 1990). In contrast, retention time is greatly increased in crusts with high pedicels when compared to crusts having little pedicellation (Barger *et al.*, unpublished data; Belnap *et al.*, unpublished data). This is likely due to the large increase in path length experienced by water travelling over a pinnacled soil crust compared to a smooth crust (Figure 7, Belnap *et al.*, 2005). The only experiment assessing the effect of rugose crusts on retention time without the complication of disturbance (see Past Studies: How Crusts Affect Runoff and Infiltration below for further discussion on the undesired side effects of disturbance treatments) showed time to ponding was positively related to crust cover ($R^2 = 0{\cdot}35$), but there was no correlation with time to runoff (Eldridge *et al.*, 1997). There are no known measures for rolling crusts. If it can be assumed that surface roughness, and thus tortuosity, dominates retention time, then it is expected that retention time will change with the soil surface type, and increase in the following order: smooth crust < bare soil < rugose crust < rolling crust < pinnacled crust (Figure 6).

Surface area for infiltration

Because smooth and rugose crusts are relatively flat, they offer little increase in the amount of soil surface area available for water infiltration. Pinnacled crusts represent the other extreme, with an increase of 100% or more in surface area on the upslope side of a typical mound (Figure 2). Rolling crusts are expected to be intermediate between rugose and pinnacled crusts (Figure 6).

Association with physical (mechanical, chemical, and vesicular) crusts

Physical crusts are transient soil surface layers which range in thickness from less than 1 mm to a few centimetres and which are structurally different than the material immediately beneath them. Most physical crusts form due to one or a combination of the following factors: the impact of raindrops, compressional forces such as animal trampling or vehicular traffic, evaporative processes (forming chemical crusts), and trapped gas bubbles (forming vesicular crusts). Biological crusts are often associated with varying degrees of physical crusting, which is known to restrict infiltration and increase runoff (Romkens *et al.*, 1990; Eldridge, 2003; Warren, 2003a). However, very little is understood about the relationship between physical and biological crusts, and there is no known data on the threshold where the strength or thickness of the physical crust impedes infiltration relative to the various aspects of the biological crusts that may enhance (or impede, in the case of smooth crusts) infiltration. Strong physical crusting is more often associated with fine-textured

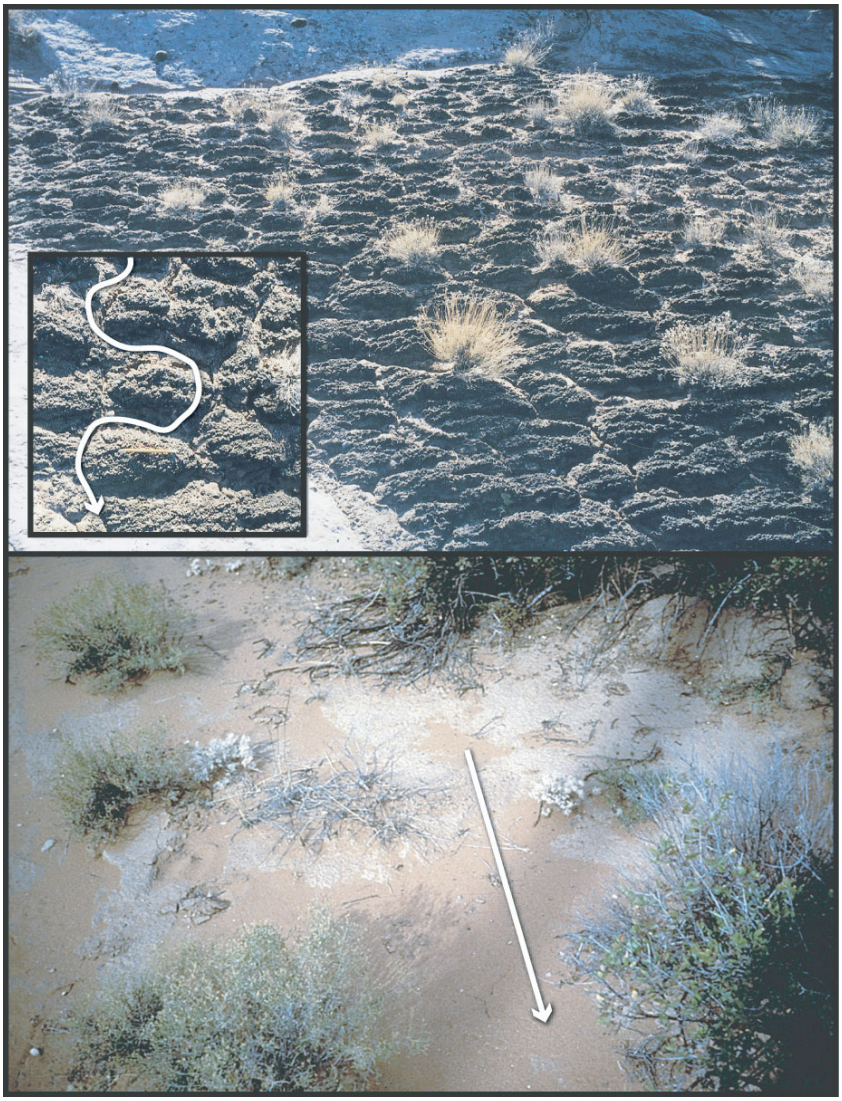

Figure 7. The path length of water leaving a site with smooth crusts is much shorter than the path length of water leaving a site with pinnacled crusts. Note that the mounds in a pinnacled crust are parallel to each other, affecting the direction of water flow

soils relative to more sandy soils. Therefore, it could be predicted that physical crusts are more likely than biological crusts to control infiltration rates on fine-textured soils. However, it has also been argued that the inherent lack of micropores in fine-textured or physically crusted soils (compared to coarse-textured soils) means that pore formation by biological crusts has a larger impact on infiltration rates of fine-textured soils than sandier soils (Warren, 2003b). Unfortunately, there is little known data to inform this debate.

Soil surface cracking

Polysaccharide secretions by crust organisms can increase the density of surface cracks on fine-textured soils (Danin *et al*., 1998; Kidron *et al*., 1999). In addition, the patchy nature of crust biomass concentrations can lead to differential drying between the upper and lower surfaces of the crust, resulting in upward curling of the polygon margins (e.g. Durrell and Shields, 1961; Danin *et al*., 1998). This cracking and lifting upwards

of the soil surface can result in greater infiltration into a surface that is otherwise fairly impermeable (Kidron *et al*., 1999). In addition, the roughness of the cracked surface lessens water velocity and allows more time for infiltration to occur. However, there is little information on the density of polysaccharides required to enhance cracking or uplifting of soil polygons, above that inherent to the soil alone.

Patterns in biological soil crust mounds

Mound formation in pinnacled crusts is initiated by ice needles pushing biologically crusted soils upwards (Belnap, 2003a). The crust organisms provide sufficient cohesion to stabilize the mounds, even after the ice needles melt. Once the surface is roughened, crust organisms preferentially colonize the east-northeast (ENE) aspects of the mounds in the northern hemisphere (George *et al*., 2000; Bowker *et al*., 2002), as it is the most favourable aspect for maximizing carbon gain in these organisms (Belnap, unpublished data). This greater biomass makes the ENE aspect less erodible than the other aspects, especially the west-southwest aspect. Continued greater growth and less erosion on the ENE result in mounds with their long axes facing ENE and running parallel to each other. If the mounds are at an angle to the slope, the path length of water leaving a site is greatly increased relative to a non-mounded slope (Figure 7) or to a slope where the mounds run parallel to the slope. The orientation of the mounds can also determine the path water takes as it leaves a site, thus influencing where it ultimately infiltrates into the soil. This patterning of soil crust mounds can mimic, on a microscale, the patterning of banded vegetation (d'Herbès *et al*., 2001) and is expected to have a similar effect on the hydrology at the appropriate scale (Greene *et al*., 2001). However, unlike banded vegetation, we do not understand the relationship between the length of the mounds or the distance between them and site characteristics likely to influence this patterning (e.g. slope degree, aspect, timing and intensity of precipitation, soil texture). Rugose and rolling crusts sometimes form small mounds, and in the northern hemisphere, these mounds are also oriented ENE. The formation process of these mounds has not been studied, although it is likely that differential growth also creates these phenomena.

Vascular plant communities

Biological crusts can influence many characteristics of vascular plant communities, including species composition, plant density, plant size, and community architecture. Plants, in turn, intercept, direct, and slow runoff water, thus influencing the location and amount of water retained on a site (Loik *et al*., 2004; Ludwig *et al*., 2005). The type and amount of influence biological crusts exert on vascular plant communities are determined by what crust type is present.

Smooth crusts increase the probability that seeds will be blown or washed from plant interspaces to nearby obstructions (e.g. plants, large rocks), as they act to flatten and smooth the soil surface (Prasse, 1999). Thus, seedlings are only infrequently found in interspaces on the smooth crust type. Instead, plants generally germinate under the canopy of nearby 'nurse' plants. Furthermore, smooth crusts are also the only crust type found to inhibit the germination of selected plant species (Boeken *et al*., 1998), although very few species have been tested. Smooth crusts can significantly increase water runoff to downslope vegetation. In hyperarid areas, this runoff is critical to plant survival; when the crusts in the interband areas are removed, downslope plants die from lack of water and nutrients. As plants die, the banding effect of the vegetation is lost, as is the ability to retain water and nutrients at the local scale (Eldridge *et al*., 2000; Eldridge *et al*., 2001).

Pinnacled and rolling crusts affect vascular plants differently than smooth crusts as they retain seeds and other resources (e.g. water, organic matter) in plant interspaces, where the seeds can germinate and establish (Belnap *et al*., 2003b). Wind tunnel experiments show, however, that when crust mounds are flattened, seeds skid off to nearby obstructions rather than staying in the plant interspace (Belnap, unpublished data). As mentioned above, the orientation of crust mounds can direct water toward, or away from, an individual plant, thus affecting survival of the plant. Seed germination and plant success are either enhanced or not affected by pinnacled and rolling crusts, with no known cases of native plants being suppressed (Belnap *et al*., 2003b). Pinnacled and rolling crusts have a high cover of nitrogen-fixing species, which increases soil fertility, plant

density, and plant biomass in crusted soils when compared to uncrusted soils (Belnap *et al*., 2003b). Pinnacled and rolling crusts also appear to increase the resistance of an ecosystem to invasion by exotic annual grasses (Larsen, 1995; Howell, 1998), thus conserving the hydrologic cycles associated with the native perennial plant communities. In wet years, the annual plants decrease water runoff and sediment production relative to the native perennial plants, but in drought years, the annuals often fail to germinate, leaving extensive areas of soils unprotected.

Very little is known about the influence of rugose crusts on vascular plant communities. These communities generally contain a high biomass of nitrogen-fixing cyanobacteria. It has been shown that nitrogen fixed by biological crusts is utilized by associated vascular plants (reviewed in Belnap, 2003c), and thus it likely results in greater plant biomass. Rugose crusts have been found to exclude the invasion of annual grasses, as do pinnacled and rolling crusts (Crisp, 1975). Unfortunately, we have no information on how this crust type might structure perennial plant placement on the local landscape.

Soil moisture retention time

Increases in crust biomass and lichen–moss cover darken soil surfaces, which increases soil temperatures (Belnap *et al*., 2003b). Therefore, greater crust biomass may result in greater evaporative losses of soil moisture. Alternatively, decreases in soil porosity associated with increased crust cover and biomass may lessen evaporative losses. There have only been a few studies on this topic, with conflicting results. Booth (1941) found there was greater soil moisture under biologically crusted surfaces compared to bare surfaces 2 days after rainfall. Rushforth and Brotherson (1982) and George *et al*. (2003) also found soil moisture was higher under lichen crusted soils compared to bare soils. Harper and Marble (1988) found that when lichen and moss cover was less than 61%, there was no difference between crusted and uncrusted soils. However, soils with a lichen and moss cover exceeding 85% dried more quickly than bare soils. Given the wide range of climate, soil, and crust types, we need more data on the effect of biological crusts before any general conclusions can be drawn. On the basis of what data we have, it is expected that soil moisture retention will vary with crust type in the following order: smooth < rugose < rolling < pinnacled (Figure 6).

Possible feedbacks among water, crusts, and soil surface features

There are many feedback loops among crust and soil features that can influence local hydrologic processes (Figure 8). For instance, the formation of mounds in pinnacled crusts slows water and increases surface roughness, thereby increasing soil infiltration. Greater soil moisture allows for greater crust carbon and nitrogen fixation, which results in greater crust biomass. Greater crust biomass increases soil surface absorptivity, soil aggregates, soil micropore formation and stability and, up to a point, may also increase soil moisture retention. The loop is closed as these factors in turn lead to greater mounding and crust biomass. Eventually, as soil biota increase soil fertility, vascular vegetation structure and biomass are increased, which further facilitates water infiltration. This model also applies to smooth crusts. However, as smooth crusts reduce surface roughness and surface porosity, their presence will also reduce water infiltration. In hyperarid areas where smooth crusts naturally occur, the reduction of water infiltration at the microscale will still enhance vascular plant biomass at the local scale (see discussion above). If smooth crusts are a result of disturbance, the reduction of water infiltration will reduce vascular plant biomass. In either case, the other relationships described in the model still hold.

BIOLOGICAL CRUSTS AND SOIL LOSS

Water velocity

The effect of BSCs on water velocity has been found to be the same as the effect of crusts on water retention time. Smooth crusts connect sand grains together, flattening and smoothing the soil surface. This

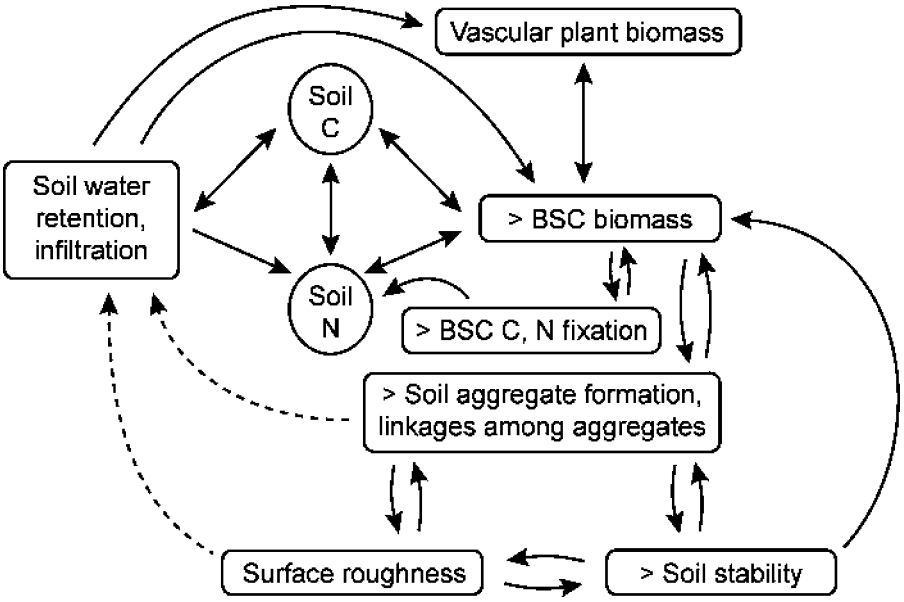

Figure 8. A conceptual model of the feedback loops in deserts connecting biological soil crusts (BSC), water and nutrient cycles, and vascular plants. The solid lines represent linkages that have been explicitly studied; the dotted lines represent hypothesized connections. It is important to note that the effect of smooth biological crusts on water infiltration and surface roughness is the opposite of other crust types (see text), and thus the type and direction of linkages noted in this model can vary with crust type

facilitates an increase in the velocity of water leaving a site (Yair, 1990). In contrast, the extreme soil surface roughness created by pinnacled crusts greatly slows time to runoff (Barger *et al*., unpublished data; Belnap *et al*., 2005). As discussed above, rugose crusts appear to influence time to ponding but not time to runoff (Eldridge *et al*., 1997). There is no known information on how rolling crusts affect water velocity. Given that their surfaces are highly absorptive and of intermediate roughness between rugose and pinnacled crusts, they are expected to slow water velocity more than rugose crusts but less than pinnacled crusts.

Soil aggregation and linkages between particles

As discussed in several sections above, soils colonized by BSCs are filled with a network of cyanobacteria and microfungal filaments, as well as the anchoring structures of mosses and lichens (Figure 3(a–f)). This provides these soils with a tremendous resistance to movement by water (e.g. Durrell and Shields, 1961; Bond and Harris, 1964; Schulten, 1985; Belnap and Gardner, 1993; Rogers and Burns, 1994; Mazor *et al*., 1996). Biological soil crusts also contribute significant amounts of organic carbon to arid soils via carbon fixation (Beymer and Klopatek, 1991) and decaying organic matter (Danin and Ganor, 1991), which also contributes to aggregate formation and thus stability. In fact, the organic mass of algal crusts can exceed that of vascular plants in some deserts (Rodin and Bazilevich, 1967). The ability of biological crusts to stabilize soils can exceed that of physical crusts (McCalla, 1946; Eldridge and Kinnell, 1997). As the number of cyanobacterial filaments and lichen and moss anchoring structures increases (Figure 4), the ability of these organisms to stabilize the soils is also increased (reviewed in Warren, 2003a, b).

Because lichen tissue and moss tissue actually protrude above and cover the soil surface, these organisms can offer complete protection to underlying soils from raindrop impacts. Cyanobacterial crusts, on the other hand, offer less protection to the soil surface, as the bulk of the cyanobacteria reside just under the surface. Although they weave a protective web throughout the soil that often connects to soil particles at the surface, raindrops still directly impact these soil particles. The type of cyanobacterial species present also affects the protective ability of cyanobacterial crusts. For instance, the filamentous *Scytonema* is more effective at

stabilizing surfaces than the unicellular *Nostoc* (Kidron *et al*., 1999). Therefore, as cyanobacterial biomass and lichen–moss cover increase, it is likely that resistance to soil erosion from raindrop impact and overland flow increases and sediment production declines. Therefore, erosion resistance is least in smooth crusts, more in rugose crust, even more in pinnacled crusts and the highest in rolling crusts (Figure 6).

Surface cracking

As discussed above, cyanobacterial crusts can increase surface cracking of fine-textured soils, and differential drying of the upper and lower layers of the crust can result in an upward curling of the polygon margins (Durrell and Shields, 1961; Danin *et al*., 1998). This upward lifting decreases velocity of runoff water, reducing its erosive force (Kidron *et al*., 1999).

PAST STUDIES: HOW CRUSTS AFFECT RUNOFF AND INFILTRATION

There has long been a debate in the literature on how the presence of BSCs influences water infiltration and runoff. A considerable literature reports that the presence of crusts increases infiltration and decreases runoff (e.g. Booth, 1941; Fletcher and Martin, 1948; Osborn, 1952; Faust, 1970; Loope and Gifford, 1972; Blackburn, 1975; Brotherson *et al*., 1983; Harper and St. Clair, 1985; Greene and Tongway, 1989; Eldridge, 1993; Perez, 1997; Seghieri *et al*., 1997); or reduces infiltration and increases runoff (e.g. Bond and Harris, 1964; Roberts and Carson, 1971; Dulieu *et al*., 1977; Brotherson *et al*., 1983; Graetz and Tongway, 1986; Dekker and Jungerius, 1990; Greene *et al*., 1990; Abaturov, 1993; Bisdom *et al*., 1993; Danin, 1996; Mazor *et al*., 1996; Kidron and Yair, 1997; Eldridge *et al*., 2000). However, other studies show no effect on either process (e.g. Faust, 1970; Dobrowolski and Williams, 1994; Eldridge *et al*., 1997; Williams *et al*., 1999). When summarizing all these studies, Warren (2003a) suggested that overall, biological crusts decreased water infiltration in sandy soils (>66% sand) and increased infiltration where clays exceeded 15%. However, almost all the studies discussed were in hot deserts, where there was no surface roughening by soil crusts. In addition, there was a great deal of variability within the studies on those finer-textured soils. Of the 13 studies presented, 7 showed that the presence of biological crusts increased infiltration, 4 showed no effect, and 2 showed biological crusts decreased infiltration.

Most studies examining the effect of biological crusts on hydrologic cycles compare crusted soils that have not been disturbed to soils where the researchers removed the crusts by various methods (e.g. trampling by humans or livestock, scalping the surface soil, driving over with vehicles or tanks, fire). Unfortunately, in addition to the removal of biological crusts, such applied disturbances result in many changes to the structure of surface and sub-surface soils (Eldridge, 2003; Warren, 2003a). Disturbance to the soil surface breaks soil aggregates, crushes macropores, disrupts physical and chemical crusts, and compacts soils. Removal of the crusts necessitates removing the top few millimetres to centimetres of soil. Therefore, subsequent experiments encounter a surface with altered soil texture, structure, and physical crusting relative to the original surface.

Using fire to kill BSCs can create hydrophobic soils, seal surfaces, and alter soil chemistry. Killing the crusts chemically still leaves polysaccharide materials in place, which are able to stabilize the soils. Thus, the complications created by applied disturbance make it extremely difficult to reach any conclusion about how crusts affect infiltration and runoff. Instead, these studies tell us how disturbance affects previously crusted soils. In addition, the role of biological crusts on infiltration and runoff may be greatly influenced by site conditions existing before the disturbance is applied. For instance, Eldridge *et al*. (1997) suggested that biological crusts increase infiltration on degraded sites, but do not affect infiltration on sites in good condition.

Another factor that makes it difficult to draw conclusions from previous studies (even comparing among undisturbed controls of the various experiments) is the lack of reported information on soil features known to influence water infiltration and runoff such as (but not limited to) the relative cover of the crust biota by species, cyanobacterial biomass, soil surface roughness, soil texture, bulk density, the degree of other types of crusting (physical, vesicular, or chemical), surface and sub-surface soil aggregate stability, percentage of

shrink-swell clays, calcrete formation, depth to bedrock, and the number of macropores. Without this type of information, it is impossible to separate the effect of biological crusts from other soil factors, as there are many that could easily override any influence of the biological crusts (e.g. a high percentage of heavy shrink-swell clays, the presence of thick vesicular crusts, a high number of macropores; Blackburn, 1975; Dobrowolski and Williams, 1994; Warren, 2003a). Results from previous studies are also difficult to compare because most studies used different instruments, methods, and even measured different variables. Many studies also utilized methods or plots too small to allow all factors, especially soil surface roughness, to influence the results. Lastly, most studies were done in hot deserts, with little data from cool or cold deserts.

Of the 41 published studies reviewed for this paper, only 8 used a gradient of existing crust types to avoid at least some of the confounding variables introduced when surfaces are disturbed to remove crusts. Of these 8, only 5 studies utilized rainfall simulators on plots large enough to integrate most or all of the factors influencing infiltration and runoff. Four of these were conducted on smooth cyanobacterial crust (Faust, 1970; Verrecchia *et al*., 1995; Kidron and Yair, 1997; Eldridge *et al*., 2000) and one on rugose crusts (Eldridge *et al*., 1997). There are also two unpublished studies on pinnacled crusts (Barger *et al*., unpublished data; Belnap *et al*., unpublished data). Whereas all these studies reported sufficient detail on the crusts and some reported vital information on soil structure, none of these studies quantitatively measured factors such as physical crusting or soil macropores. This makes it difficult to assess if the results obtained were the influence of crusts or other soil features.

However, there were consistent results among the studies within a particular crust type. All four studies on smooth crusts found that the presence of algal crusts reduced infiltration and increased runoff. The two unpublished studies on pinnacled crusts both found that as crust development increased (as measured by species richness, biomass, and surface roughness of the biological crust), so did total infiltration. The one study on rugose crusts in Australia showed no effect of soil crusts on runoff. Despite this consistency among crust types, we still need far more data before any generalizations are made about the influence of BSCs on infiltration and runoff.

To address the above issues, we need studies designed to explicitly address how biological crusts influence infiltration and runoff relative to other soil factors, without influencing these factors by applying disturbance. Such experiments need to use standardized equipment and measures on sample areas that (1) are large enough to integrate all the ways crusts may influence infiltration and runoff or (2) have specific characteristics that allow separation of individual factors influencing infiltration and runoff (e.g. the relative effect of clogging vs creating micropores). In addition, such studies need to avoid disturbance that may impact other surface and sub-surface soil characteristics. One approach would be to measure infiltration and runoff on a range of naturally occurring crust covers (*sensu* Eldridge *et al*., 1997). Another would be to inoculate soils with similar surface and sub-surface characteristics with crust organisms (*sensu* Faust, 1970), with experiments performed after the crusts are formed. However, all studies need to control for underlying soil factors if we are to truly elucidate the role of biological crusts. We also need new, creative ways to approach this question. For instance, Ladyman *et al*. (1993) reasoned that greater infiltration would transfer more calcium carbonate to depth in calcareous desert soils. They then used pH changes between the surface and sub-surface soils to investigate relative infiltration among soil crust types.

PAST STUDIES: HOW CRUSTS INFLUENCE SEDIMENT PRODUCTION

In contrast to the conflicting results on how biological crusts affect infiltration and runoff, there is a general consensus among studies in all regions that biological crusts significantly reduce sediment production from experimental sites (e.g. Booth, 1941; Fletcher and Martin, 1948; Osborn, 1952; Faust, 1970, 1971; Mücher *et al*., 1988; Chartres and Mücher, 1989; Tchoupopnou, 1989; Greene *et al*., 1990; Kinnell *et al*., 1990; Eldridge, 1993; Eldridge and Greene, 1994; Eldridge and Kinnell, 1997). There are a few exceptions, but they are rare and appear restricted to smooth crusts on sand dunes (Warren, 2003b). As with the research

on infiltration and runoff, most of these studies compare undisturbed crusts with those disturbed by the researcher, making it difficult to draw definitive conclusions. However, because almost all studies obtained the same result, information on sediment production appears more reliable than that on infiltration and runoff. In addition, the studies that did not rely on disturbance treatments (e.g. Tchoupopnou, 1989; Yair, 1990; Eldridge and Greene, 1994; Eldridge and Kinnell, 1997) all found soil stability increased as crust biomass, cover, and development increased.

CONCLUSIONS

Although previous studies have highlighted many aspects of BSCs that can, or are likely to, influence local hydrologic patterns, the role of these organisms in upland hydrologic patterns is far from well understood. The most fundamental question that remains unanswered is the relative contribution of different crust types to infiltration and runoff relative to other soil factors such as texture and sub-surface structure. Answering this question will require carefully executed studies, creative thinking, and perhaps a change in the scale of studies.

Future changes in land use and climate are likely to have a negative effect on the presence and development of BSCs. Increased human use of drylands is expected to convert many lichen–moss crusts to cyanobacterial crusts and to flatten many currently roughened surfaces. In addition, increasing air temperature is likely to decrease lichen cover in many crusts. Therefore, it is probable that the current influence of BSCs on infiltration, runoff, and sediment production will be greatly altered in the future.

ACKNOWLEDGEMENTS

The author would like to thank Sue Phillips, Tina Kister, Shelley Pistorius, Nichole Barger, and Jeff Herrick for help on graphics, editing, and extensive discussions on the role of biological crusts in hydrologic function of drylands. This work was supported by the US Geological Survey.

REFERENCES

Abaturov BD. 1993. Alteration of small relief forms of the hydrophysical properties of heavy loam soils in the semidesert zone by grazing. *Eurasian Soil Science* **25**: 17–28.

Avnimelech Y, Nevo Z. 1964. Biological clogging of sands. *Soil Science* **98**: 222–226.

Belnap J. 2003a. Comparative structure of physical and biological soil crusts. In *Biological Soil Crusts: Structure, Function, and Management*, Belnap J, Lange OL (eds). Springer-Verlag: Berlin; 177–191.

Belnap J. 2003b. Microbes and microfauna associated with biological soil crusts. In *Biological Soil Crusts: Structure, Function, and Management*, Belnap J, Lange OL (eds). Springer-Verlag: Berlin; 167–174.

Belnap J. 2003c. Factors influencing nitrogen fixation and nitrogen release in biological soil crusts. In *Biological Soil Crusts: Structure, Function, and Management*, Belnap J, Lange OL (eds). Springer-Verlag: Berlin; 241–261.

Belnap J, Büdel B, Lange OL. 2003a. Biological soil crusts: characteristics and distribution. In *Biological Soil Crusts: Structure, Function, and Management*, Belnap J, Lange OL (eds). Springer-Verlag: Berlin; 3–30.

Belnap J, Prasse R, Harper KT. 2003b. Influence of biological soil crusts on soil environments and vascular plants. In *Biological Soil Crusts: Structure, Function, and Management*, Belnap J, Lange OL (eds). Springer-Verlag: Berlin; 281–300.

Belnap J, Gardner JS. 1993. Soil microstructure in soils of the Colorado Plateau: the role of the cyanobacterium *Microcoleus vaginatus*. *Great Basin Naturalist* **53**: 40–47.

Belnap J, Phillips SL, Miller ME. 2004. Response of desert biological soil crusts to alterations in precipitation frequency. *Oecologia* **141**: 306–316, ISSN: 0029–8549 (Paper) 1432–1939 (Online).

Belnap J, Phillips SL, Troxler T. 2006. Soil lichen and moss cover and species richness can be highly dynamic: the effects of invasion by the annual exotic grass *Bromus tectorum* and the effects of climate on biological soil crusts. *Applied Soil Ecology* **32**: 63–76.

Belnap J, Welter JR, Grimm NB, Barger NN, Ludwig JA. 2005. Linkages between microbial and hydrologic processes in arid and semi-arid watersheds. *Ecology* **86**: 298–307.

Beymer RJ, Klopatek JM. 1991. Potential contribution of carbon by microphytic crusts in pinyon-juniper woodlands. *Arid Soil Research and Rehabilitation* **5**: 187–198.

Bisdom EBA, Dekker LW, Schoute JFT. 1993. Water repellency of sieve fractions from sandy soils and relationships with organic material and soil structure. *Geoderma* **56**: 105–118.

Blackburn WH. 1975. Factors influencing infiltration and sediment production of semiarid rangelands in Nevada. *Water Resources Research* **11**: 929–937.

Blum OB. 1973. Water relations. In *The Lichens*, Ahmadjian V (ed.). Academic Press: New York; 697.

Boeken B, Lipchin C, Gutterman Y, van Rooyen N. 1998. Annual plant community responses to density of small-scale soil disturbances in the Negev desert of Israel. *Oecologia* **114**: 106–117.

Bond RD, Harris JR. 1964. The influence of the microflora on physical properties of soils. I. Effects associated with filamentous algae and fungi. *Australian Journal of Soil Research* **2**: 111–122.

Booth WE. 1941. Algae as pioneers in plant succession and their importance in erosion control. *Ecology* **22**: 38–46.

Bowker M, Reed SC, Belnap J, Phillips S. 2002. Temporal variation in community composition, pigmentation, and F_v/F_m of desert cyanobacterial soil crusts. *Microbial Ecology* **43**: 13–25.

Brady NC, Weil RR. 1996. *The Nature and Properties of Soils* (11th edn). Prentice Hall: Upper Saddle River, NJ.

Brotherson JD, Rushforth SB, Johansen JR. 1983. Influence of cryptogamic crusts on moisture relationships of soils in Navajo national monument, Arizona. *Great Basin Naturalist* **43**: 73–78.

Büdel B, Lange OL. 2003. Synopsis: comparative biogeography and ecology of soil-crust biota and communities. In *Biological Soil Crusts: Structure, Function, and Management*, Belnap J, Lange O (eds). Springer-Verlag: Berlin; 141–152.

Campbell SE. 1979. Soil stabilization by a prokaryotic desert crust: implications for Precambrian land biota. *Origins of Life* **9**: 335–348.

Catcheside DG. 1980. *Mosses of South Australia*. D.J. Woolman, Government Printer: Adelaide, South Australia.

Chartres CJ, Mücher HJ. 1989. The effects of fire on the surface properties and seed germination in two shallow monoliths from a rangeland soil subjected to simulated raindrop impact and water erosion. *Earth Surface Processes and Landforms* **14**: 407–417.

Crisp MD. 1975. *Long term change in arid zone vegetation at Koonamore*. PhD. dissertation, Botany Department, University of Adelaide, South Australia, Australia, Unpublished.

Danin A. 1996. *Plants of desert dunes*. Springer-Verlag: Berlin.

Danin A, Ganor E. 1991. Trapping of airborne dust by mosses in the Negev Desert, Israel. *Earth Surface Processes and Landforms* **16**: 153–162.

Danin A, Yaalon DH. 1982. Silt plus clay sedimentation and decalcification during plant succession in sands of the Mediterranean coastal plain of Israel. *Israel Journal of Earth Sciences* **31**: 101–109.

Danin A, Dor I, Sandler A, Amit R. 1998. Desert crust morphology and its relations to microbiotic succession at Mt. Sedom, Israel. *Journal of Arid Environments* **38**: 161–174.

Dekker LW, Jungerius PD. 1990. Water repellency in the dunes with special reference to the Netherlands dunes of the European coasts. *Catena Supplement* **18**: 173–183.

d'Herbès J-M, Valentin C, Tongway DJ, Leprun J-C. 2001. Banded vegetation patterns and related structures. In *Banded Vegetation Patterning in Arid and Semiarid Environments: Ecological Processes and Consequences for Management*, Tongway DJ, Valentin C, Seghieri J (eds). Springer-Verlag: New York; 1–19.

Dobrowolski JP, Williams JD. 1994. Effects of disturbance by tracked vehicles on wind and water erosion, Prepared for US Department of Agriculture, Shrub Science Lab, Utah State University: Provo, Logan, UT.

Dulieu D, Gaston A, Darley J. 1977. La dégradation des pâturages de la région N'Djamena (République du Tchad) en relation avec la présence de cyanophycées psammophiles–etude préliminaire. *Revue D Elevage Et De Medecine Veterinaire Des Pays Tropicaux* **30**: 181–190.

Durrell LW, Shields LM. 1961. Characteristics of soil algae relating to crust formation. *Transactions of the American Microscopical Society* **80**: 73–79.

Eldridge DJ. 1993. Cryptogam cover and soil surface condition: effects on hydrology on a semiarid woodland soil. *Arid Soil Research and Rehabilitation* **7**: 203–217.

Eldridge DJ. 2003. Biological soil crusts and water relations in Australian deserts. In *Biological Soil Crusts: Structure, Function, and Management*, Belnap J, Lange O (eds). Springer-Verlag: Berlin; 315–325.

Eldridge DJ, Greene RSB. 1994. Assessment of sediment yield by splash erosion on a semi-arid soil with varying cryptogam cover. *Journal of Arid Environments* **26**: 221–232.

Eldridge DJ, Kinnell PIA. 1997. Assessment of erosion rates from microphyte-dominated calcareous soils under rain-impacted flow. *Australian Journal of Soil Research* **35**: 475–489.

Eldridge DJ, Tozer ME, Slangen S. 1997. Soil hydrology is independent of microphytic crust cover: Further evidence from a wooded semiarid Australian rangeland. *Arid Soil Research and Rehabilitation* **11**: 113–126.

Eldridge DJ, Lepage M, Bryannah MA, Ouedraogo P. 2001. Soil biota in banded landscapes. In *Banded Vegetation Patterning in Arid and Semiarid Environments: Ecological Processes and Consequences for Management*, Tongway DJ, Valentin C, Seghieri J (eds). Springer-Verlag: New York; 105–131.

Eldridge DJ, Zaady E, Shachak M. 2000. Infiltration through three contrasting biological soil crusts in patterned landscapes in the Negev, Israel. *Catena* **40**: 323–336.

Faust WF. 1970. The effect of algal-mold crusts on the hydrologic processes of infiltration, runoff, and soil erosion under simulated conditions. Master of Science, Department of Watershed Management, University of Arizona, Tucson, AZ.

Faust WF. 1971. Blue-green algal effects on some hydrologic processes at the soil surface. *Hydrology and Water Resources in Arizona and the Southwest: Proceedings of the 1971 Meetings of the Arizona Section–American Water Resources Association and Hydrology Section*. Arizona Academy of Science: Tempe, Arizona; 99–105.

Fletcher JE, Martin WP. 1948. Some effects of algae and molds in the rain-crust of desert soils. *Ecology* **29**: 95–100.

Galun M, Bubrick P, Garty J. 1982. Structural and metabolic diversity of two desert-lichen populations. *Journal of the Hattori Botanical Laboratory* **53**: 321–324.

Garcia-Pichel F, Belnap J. 1996. Microenvironments and microscale productivity of cyanobacterial desert crusts. *Journal of Phycology* **32**: 774–782.

George DB, Davidson DW, Schliep KC, Patrell-Kim LJ. 2000. Microtopography of Microbiotic Crusts on the Colorado Plateau, and the Distribution of Component Organisms. *Western North American Naturalist* **60**: 343–354.

George DB, Roundy BA, St. Clair LL, Johansen JR, Schaalje GB, Webb BL. 2003. The effects of microbiotic soil crusts on soil water loss. *Arid Land Research and Management* **17**: 113–125.

Graetz RD, Tongway DJ. 1986. Influence of grazing management on vegetation, soil structure and nutrient distribution and the infiltration of applied rainfall in a semi-arid chenopod shrubland. *Australian Journal of Ecology* **11**: 347–360.

Greene RSB. 1992. Soil physical properties of three geomorphic zones in a semi-arid mulga woodland. *Australian Journal of Soil Research* **30**: 55–69.

Greene RSB, Chartres CJ, Hodgkinson KC. 1990. The effects of fire on the soil in a degraded semi-arid woodland. I. Cryptogam cover and physical and micromorphological properties. *Australian Journal of Soil Research* **28**: 755–777.

Greene RSB, Tongway DJ. 1989. The significance of (surface) physical and chemical properties in determining soil surface condition of red earths in rangelands. *Australian Journal of Soil Research* **27**: 213–225.

Greene RSB, Valentin C, Esteves M. 2001. Runoff and erosion processes. In *Banded Vegetation Patterning in Arid and Semi-arid Environment-Ecological Processes and Consequences for Management*, Valentin C, Tongway D, Seghieri J, d'Herbes JM (eds). Springer-Verlag: 52–76.

Harper KT, Marble JR. 1988. A role for nonvascular plants in management of arid and semiarid rangelands. In *Vegetational Science Applications for Rangeland Analysis and Management*, Tueller PT (ed.). Kluwer Academic Press: Dordrecht, Netherlands; 135–169.

Harper KT, St. Clair LL. 1985. Cryptogamic soil crusts on arid and semiarid rangelands in Utah: effects on seedling establishment and soil stability. BLM Contract No. BLM AA 851-CTI-48. Department of Botany and Range Science, Brigham Young University, Provo, UT.

Howell W. 1998. *Germination and Establishment of Bromus Tectorum L. in Relation to Cation Exchange Capacity, Seedbed, Litter, Soil Cover and Water*, Prescott College: Prescott, AZ.

Kidron GJ, Yair A. 1997. Rainfall-runoff relationship over encrusted dune surfaces, Nizzana, Western Negev, Israel. *Earth Surface Processes and Landforms* **22**: 1169–1184.

Kidron GJ, Yaalon DH, Vonshak A. 1999. Two causes for runoff initiation on microbiotic crusts: hydrophobicity and pore clogging. *Soil Science* **164**: 18–27.

Kinnell PIA, Chartres CJ, Watson CL. 1990. The effects of fire on the soil in a degraded semi-arid woodland. II. Susceptibility of the soil to erosion by shallow rain-impacted flow. *Australian Journal of Soil Research* **28**: 779–794.

Ladyman JAR, Muldavin E, Fletcher R. 1993. *Pattern and Relationships of Terrestrial Cryptogam Cover in Two Pinon-Juniper Communities in New Mexico*, RM-236. US Department of Agriculture, Forest Service: Santa Fe, New Mexico.

Larsen KD. 1995. Effects of microbiotic crusts on the germination and establishment of three range grasses. Master of Science, Interdisciplinary Studies, Plant Soil Ecology, Boise State University, Boise, ID.

Loik ME, Breshears DD, Laurenroth WK, Belnap J. 2004. Climatology and ecohydrology of precipitation pulses in arid and semiarid ecosystems of the western USA. *Oecologia* **141**: 269–281.

Loope WL, Gifford GF. 1972. Influence of a soil microfloral crust on select properties of soils under pinyon-juniper in southeastern Utah. *Journal of Soil and Water Conservation* **27**: 164–167.

Ludwig JA, Wilcox BP, Breshears DD, Tongway DJ, Imesone AC. 2005. Vegetation patches and runoff–erosion as interacting ecohydrological processes in semiarid landscapes. *Ecology* **86**: 288–297.

Mazor G, Kidron GJ, Vonshak A, Abeliovich A. 1996. The role of cyanobacterial exopolysaccharides in structuring desert microbial crusts. *FEMS Microbiology Ecology* **21**: 121–130.

McCalla TM. 1946. Influence of some microbial groups on stabilizing soil structure against falling water drops. *Soil Science Society of America Proceedings* **11**: 260–263.

McIntyre DS. 1958. Soil splash and the formation of surface crusts by raindrop impact. *Soil Science* **81**: 261–266.

Mücher HJ, Chartres CJ, Tongway DJ, Greene RSB. 1988. Micromorphology and significance of the surface crusts of soils in rangelands near Cobar, Australia. *Geoderma* **42**: 227–244.

Osborn B. 1952. Range soil conditions influence water intake. *Journal of Soil and Water Conservation* **7**: 128–132.

Perez FL. 1997. Microbiotic crusts in the high equatorial Andes, and their influence on Paramo soils. *Catena* **31**: 173–198.

Poelt MJ, Baumgärtner H. 1964. Über Rhizenenstränge bei placodialen Flechten. *Österreichischen Botanischen Zeitschrift* **110**: 194–269.

Prasse R. 1999. *Experimentelle Untersuchungen an Gefäßpflanzen-populationen Auf Verschiedenen Geländeoberflächen in einem Sandwüstengebiet (Experimental Studies with Populations of Vascular Plants on Different Soil Surfaces in a Sand Desert Area)*. Universitätsverlag Rasch: Osnabrück, Germany.

Reynolds R, Belnap J, Reheis M, Lamothe P, Luiszer F. 2001. Aeolian dust in Colorado Plateau soils: nutrient inputs and recent change in source. *Proceedings of the National Academy of Sciences* **98**: 7123–7127.

Roberts FJ, Carson BA. 1971. Water repellence in sandy soils of south-western Australia. *Australian Journal of Soil Research* **10**: 35–42.

Rodin LE, Bazilevich NI. 1967. *Production and mineral cycling in terrestrial vegetation*. Translated by Fogg GE, Edited by Fogg GE. Oliver and Boyd: Edinburgh, Scotland.

Rogers RW. 1989. Blue-green algae in southern Australian rangeland soils. *Australian Rangelands Journal* **11**: 67–73.

Rogers SL, Burns RG. 1994. Changes in aggregate stability, nutrient status, indigenous microbial populations, and seedling emergence, following inoculation of soil with *Nostoc muscorum*. *Biology and Fertility of Soils* **18**: 209–215.

Romkens MJM, Prasad SN, Whisle FD. 1990. Surface sealing and infiltration. In *Process Studies in Hillslope Hydrology*, Anderson MG, Burt IP (eds). John Wiley and Sons: 127–172.

Rushforth SR, Brotherson JD. 1982. Cryptogamic soil crusts in the deserts of North America. *American Biology Teacher* **44**: 472–475.

Sanders WB. 1994. Role of rhizomorphs in thallus propagation and substrate colonization. *Cryptogamic Botany* **4**: 283–289.

Schulten JA. 1985. Soil aggregation by cryptogams of a sand prairie. *American Journal of Botany* **72**: 1657–1661.

Seghieri J, Galle S, Rajot JL, Ehrmann M. 1997. Relationships between soil moisture and growth of herbaceous plants in a natural vegetation mosaic in Niger. *Journal of Arid Environments* **36**: 87–101.

Tchoupopnou E. 1989. Splash from microphytic soil crusts following simulated rain. Master of Science, Range Science, Utah State University, Logan, UT.

Thurow TL. 1991. Hydrology and erosion. In *Grazing Management An Ecological Perspective*, Heitschmidt RK, Stuth JW (eds). Timber Press: Portland, Oregon; 141–177.

Verrecchia E, Yair A, Kidron GJ, Verrecchia K. 1995. Physical properties of the psammophile cryptogamic crust and their consequences to the water regime of sandy soils, north-western Negev Desert, Israel. *Journal of Arid Environments* **29**: 427–437.

Warren SD. 2003a. Synopsis: influence of biological soil crusts on arid land hydrology and soil stability. In *Biological Soil Crusts: Structure, Function, and Management*, Belnap J, Lange OL (eds). Springer-Verlag: Berlin; 349–360.

Warren SD. 2003b. Biological soil crusts and hydrology cycles in North American deserts. In *Biological Soil Crusts: Structure, Function, and Management*, Belnap J, Lange OL (eds). Springer-Verlag: Berlin; 327–337.

Williams JD, Dobrowolski JP, West NE. 1999. Microbiotic crust influence on unsaturated hydraulic conductivity. *Arid Soil Research and Rehabilitation* **13**: 145–154.

Yair A. 1990. Runoff generation in a sandy area–the Nizzana sands, western Negev, Israel. *Earth Surface Processes and Landforms* **15**: 597–609.

Zaady E, Levacov R, Shachak M. 2004. Application of the herbicide, simazine, and its effect on soil surface parameters and vegetation in a patchy desert landscape. *Arid Land Research and Management* **18**: 397–410.

25 Biological Soil Crusts and Wind Erosion

J. Belnap

25.1 Introduction

Wind is an important erosive force in deserts, where limited cover of vascular plant material offers little soil-surface protection. Dust deposition by wind often exceeds that of fluvial deposition in these drier regions (Goudie 1978; Williams et al. 1995). Sediment production from soil surfaces occurs when wind forces exceed soil threshold friction velocities (TFV: the wind velocity needed to detach particles from soil surfaces). Decreased TFVs are directly associated with increased sediment movement. Soil fine particles are preferentially lost over larger sand particles (Leys 1990; Williams et al. 1995). Increased sediment movement can result in many direct and indirect problems for semiarid and arid ecosystems. Soils weather slowly from parent rock in deserts, often taking 5000–10 000 years (Webb and Wilshire 1983). Much of the soil fine material found in these regions is from atmospheric deposition (Danin and Yaalon 1982). Soils from the Colorado Plateau deserts show that most fine particles are derived from surrounding igneous mountains. Current deposition rates in these regions are low and when soils are disturbed, loss rates may far exceed deposition (Gillette et al. 1980; Offer et al. 1992; Belnap and Gillette 1997,1998; Reynolds et al. 1998).

Most of the soil photosynthetic productivity and nitrogen (N) fixation in desert soils is concentrated within 3 mm of the surface (Garcia-Pichel and Belnap 1996; see Chap. 16). Thus, only a little soil loss can significantly reduce C and N inputs from these organisms (see Chaps. 18, 19). In addition, the top few mm of soil contain a much higher percentage of soil fine particles than underlying soils (Danin and Ganor 1991; Verrecchia et al. 1995). Loss of soil fines can reduce site productivity, as plant-essential nutrients are often bound to these particles. Burial of nearby biological soil crusts from windblown sediments generally means death for the photosynthetic components of the soil crusts, further reducing fertility. Reduced fertility of systems is one of the most definitive, and problematic, aspects of desertification. Worldwide increases in windborne sediments are amply documented (Goudie 1978; Kovda 1980; Tsoar and Pye 1987).

Ecological Studies, Vol. 150
J. Belnap and O.L. Lange (eds.) Biological Soil Crusts: Structure, Function, and Management
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Both plant and soil characteristics influence wind erosion. In deserts, vascular plants are generally short with sparsely vegetated stems, and very large spaces occur between individuals. Plant litter cover is also very low. Thus, plant materials in semiarid and arid regions offer limited protection to soils from wind erosion. In such environments, biological soil crusts can play a critical role in soil stabilization.

25.2 The Influence of Undisturbed Biological Soil Crusts on Wind Erosion

Soil characteristics that reduce wind erosion include rock cover, high salt or calcium carbonate content, high clay/silt content, physical crusts, and extensive biological soil-crust cover. Where rocks form a pavement, soils are completely armored from wind erosion. However, many desert soils are not covered by pavement, and any soil between rocks is still vulnerable to wind erosion (Gillette et al. 1980; Musick 1998). Undisturbed, fine-textured desert soils have many of the above characteristics and are most often stable until disturbed (Gillette et al. 1980). When disturbed, however, the physical crust crumbles into tiny particles and most soil-surface protection is lost until the next rain storm reforms the crust. However, when biological crusts are disturbed, large aggregrates are left, bound together by unbroken filaments (Gillette et al. 1980; J.E. Herrick and J. Belnap, unpubl.). Coarse-textured soils are inherently more erodible than fine-textured soils, as they have less salt, clay and other characteristics that lead to significant surface physical crusting. Therefore, coarse soils are generally dependent on rocks and biological soil crusts for surface protection (Williams et al. 1995; Leys and Eldridge 1998). When different surfaces are tested under naturally occurring wind speeds, ranking of the inherent resistance of soils to erosion is: desert pavements=lichen/moss biological soil crusts > playa centers > playa edges > cyanobacterial soil crusts >disturbed clay soils > alluvial and aeolian sandy soils > sand dunes = disturbed sandy or silty soils (Gillette et al. 1980; Belnap and Gillette 1997, 1998).

Many studies worldwide have shown that biological soil crusts can be a critical factor in reducing soil erosion by wind (Dulieu et al. 1977; Van den Ancker et al. 1985; Tsoar and Møller 1986; Danin et al. 1989; Pluis 1994; Williams et al. 1995; Belnap and Gillette 1997, 1998; Marticorena et al. 1997; Leys and Eldridge 1998). Polysaccharides extruded by cyanobacteria and microfungi entrap and bind soil particles together, creating larger soil aggregates. Polysaccharides also then link these larger aggregates together (Belnap and Gardner 1993). These larger, linked aggregates require greater wind velo-

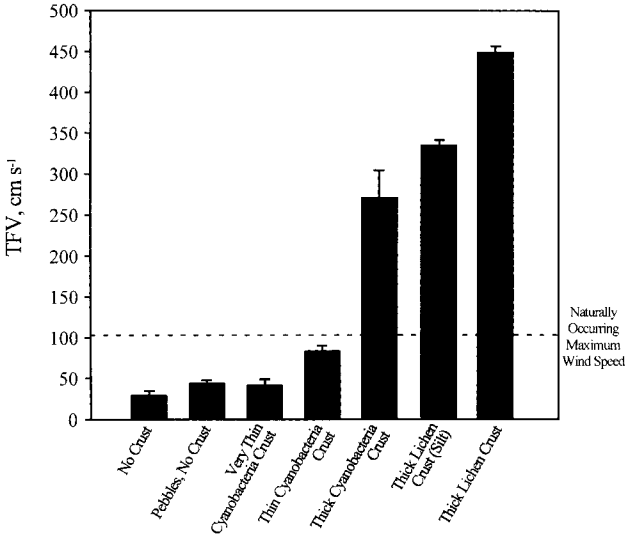

Fig. 25.1. Threshold friction velocities (*TFV*) of soil surfaces with different levels of biological soil-crust development. (After Belnap and Gilette 1998)

city to move than single grains (Gillette et al. 1980; Marticorena et al. 1997); this can be seen vividly with SEM photos (see Chap. 15; Van den Ancker et al. 1985; Danin et al. 1989; Chartes 1992; Belnap and Gardner 1993; Eldridge and Greene 1994). In laboratory wind-tunnel trials, cyanobacteria appear better able to protect soil surfaces than green algae. Cyanobacteria are generally longer and larger than green algae, and thus better able to connect soil particles together (McKenna-Neuman et al. 1996).

Soil resistance to wind erosion increases with biological crust development on all substrates tested (Fig. 25.1). While any level of biological crust development reduces soil loss by wind, both silt and sandy soils with the greatest erosion resistance are those with the most well-developed biological crusts. Even undisturbed, chemically-killed crusts (leaving the polysaccharide material intact) continue to protect the soil surface from erosion, at least temporarily (Williams et al. 1995). In most cases, well-developed crusts can withstand winds well above those recorded at field sites, and so offer complete protection from wind erosion, even in coarse soils (Leys 1990; Williams et al. 1995; Belnap and Gillette 1997,1998; Leys and Eldridge 1998).

25.3 Crust Disturbance and Wind Erosion

Biological soil crusts are highly susceptible to disturbance, especially in soils with low aggregate stability such as sands (see Chap. 27; Webb and Wilshire 1983; Belnap and Gardner 1993). Cyanobacterial filaments, lichens, and

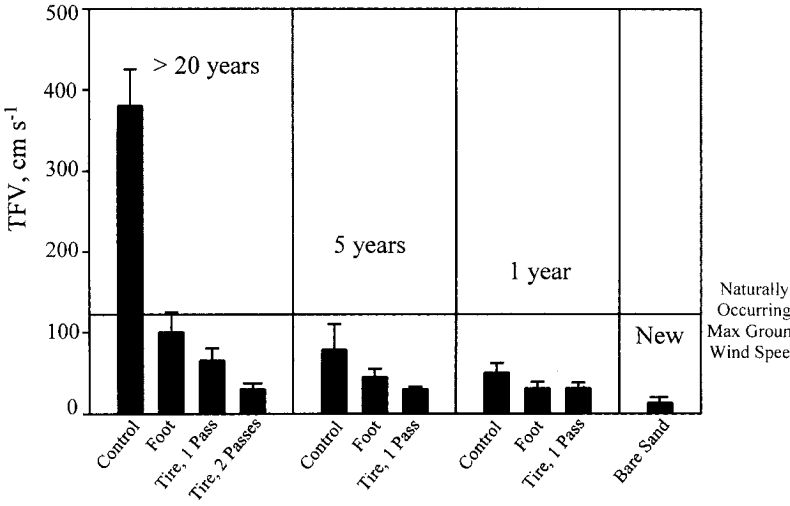

Fig. 25.2. Threshold friction velocities (*TFV*) and sediment production of control (undisturbed) and vehicle-disturbed (two passes) surfaces in Joshua Tree National Park, CA. Seven of eight control sites have TFVs above maximum field-recorded wind speeds; seven of eight disturbed sites have TFVs below recorded wind speeds. Sediment production is increased 2–36× with disturbance. (J. Belnap, unpubl.)

mosses are brittle when dry, and crush easily when subjected to compressional or shear forces incurred by activities such as trampling or vehicular traffic. Such disturbances break apart soil aggregates and the connections between them. Thus, TFV decreases significantly when the soil crusts are disturbed. Belnap and Gillette (1997) showed soil surface TFV in a sandy soil decreased by 73–92 % when moderate disturbance was applied (Fig. 25.2). Leys and Eldridge (1998) reported that moderate disturbance reduced soil TFV by 57 % in a loamy soil and by 40 % in sandy soils. Williams et al. (1995) found removing crust from silty soils decreased TFV by 50 %. Two passes with a vehicle decreased TFV in silty soils up to 96 % in coarse sandy and silty soils (J. Belnap, unpubl.). Belnap and Gillette (1998) applied the same moderate disturbance to a range of adjacent soil types. Physically-crusted playa soils with no biological crust showed the greatest impact with disturbance, as crushing of the mineral crust left the surface with virtually no erosion protection. Silty and coarse-structured soils covered with varying types of biological soil crusts showed an intermediate response, with gravel soils being the least compromised (Fig. 25.1). Severe disturbances show greater decreases in TFV than moderate disturbances (Leys and Eldridge 1998).

As TFV decreases, sediment production increases; thus, sediment loss is increased on disturbed surfaces. In Australia, Leys (1990) showed a fivefold increase in sediment production when a crusted surface was disturbed. Leys

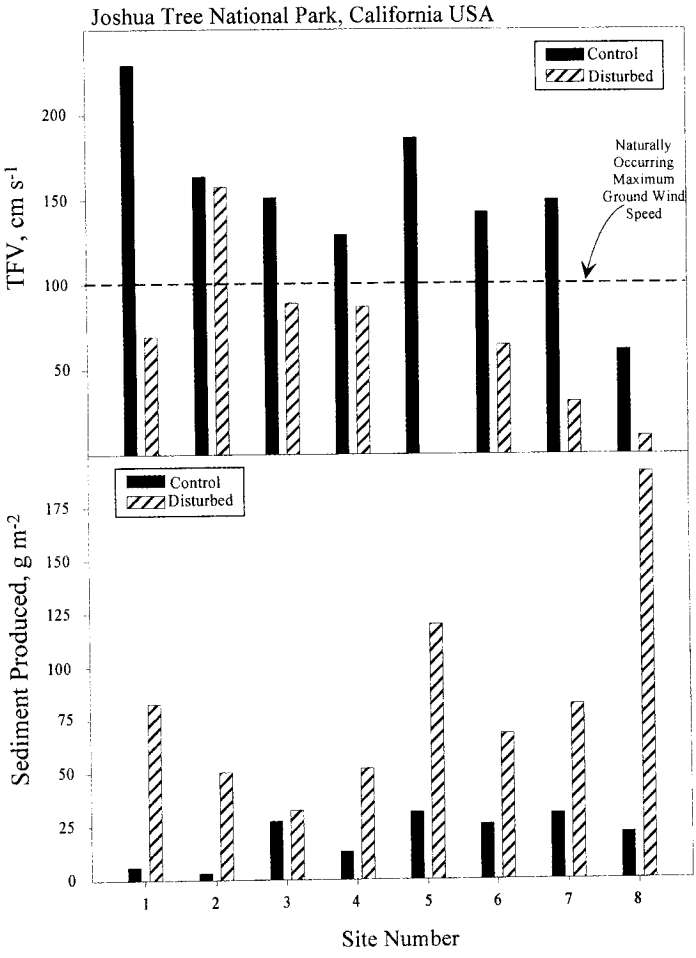

Fig. 25.3. Threshold friction velocities (*TFV*) of soil surfaces. Experimental disturbances were applied to four surfaces in SE Utah with different disturbance histories: undisturbed (>20 years), lichen-moss soil crusts; crust vehicle-disturbed 5 years previously (currently cyanobacterially dominated); crust vehicle-disturbed 1 year previously (currently cyanobacterially dominated) and newly disturbed lichen-moss crust. These soils were then walked and driven over, except for controls. All differences within a soil type are significantly different ($p<0.05$). TFVs of undisturbed crusts are above maximum field-recorded wind speeds, while those for all other surfaces are below recorded wind speeds, and thus subject to wind erosion. (After Belnap and Gilette 1997)

and Eldridge (1998) showed a fivefold increase in sediment loss from a loamy soil and a fourfold increase from sandy soils when soil crusts were severely disturbed by raking (however, due to greater erodibility in sandy soil, much more total sediment was lost from the sandy site). Williams et al. 1995 showed a fivefold increase in sediment loss when crusts were scalped from a silty soil. Figure 25.2 shows 2- to 35-fold increases in sediment production at high spring wind speeds when crust-covered sandy loam soils in the Mojave Desert were disturbed by vehicle tracks. As disturbance increases in severity, more aggregates are crushed, resulting in greater soil loss with greater disturbance levels (Leys and Eldridge 1998).

Disturbance type can affect wind erodibility. Hoof and human footprints have less effect on soil TFV than vehicle tracks in sandy and some silty soils (Belnap and Gillette 1997, 1998). In other silty soils, hoof prints have more impact than vehicle tracks (Belnap and Gillette 1998). This response is probably dependent on the depth of the print in a given soil, as deeper, discrete prints would have greater protection from wind than shallow prints or continuous vehicle tracks.

The condition of the biological soil crust prior to disturbance can affect the wind erodibility of a surface after the new disturbance. Disturbance in well-developed, undisturbed lichen-moss soil crusts have less effect on TFVs than disturbance to crusts that are recovering from impacts (Fig 25.3; Belnap and Gillette 1997). Footprints and one pass with a vehicle in an undisturbed lichen-moss crust have less impact than the same disturbance on a crust disturbed 5 years ago, 1 year ago, or just recently, as undisturbed crusts have a buildup of soil-binding polysaccharide material both at and below the soil surface that is lacking in crusts that have recently been disturbed. Nearby disturbances can also have a detrimental effect on the stability of soil surfaces. Sediment produced from such disturbances can "sandblast" adjacent crusts and erode them at a much faster than normal rate. Thus, a small disturbance can trigger much larger impacts (Belnap and Gillette 1997; Evans and Johansen 1999).

25.4 Recovery of Wind Resistance

Because crustal organisms are only metabolically active when wet, re-establishment time is slow in arid systems. Recovery is faster under plant canopies than shrub interspaces (see Chap. 27), but soils in plant interspaces are more vulnerable to wind erosion. Experiments show that sandy soils can remain susceptible to monthly maximum winds for at least 5 years after disturbance, and to annual maximum winds for at least 10 years after disturbance (Fig. 25.2).

Although silty alluvial and sandy soils showed a similar response to new vehicle disturbance (83 vs. 74 % TFV decline), silty soils show a much faster recovery rate than sandy soils. Silty soils are able to form a thin physical crust after even a light rain that increases TFV by 65 %. In contrast, sandy soils with no physical crusting showed little TFV recovery after 5 years (Belnap and Gillette 1997).

25.5 Conclusions

All studies show that biological soil crusts play a significant role in reducing soil loss by wind. Degree of crustal development parallels amount of protection from wind erosion. As coarse soils are inherently more erodible than silt soils, and do not generally form physical crusts, the protection offered by biological soil crusts is especially important in coarse soils. Disturbance to crusts results in decreased TFV and increased sediment production. This response is related to the severity of disturbance; to the biomass, species composition, and physical structure of the soil crusts; and to soil characteristics such as texture, physical crusting, and vesicular horizons. However, with the limited number of data sets available, it is not yet possible to develop generalizations predicting the relative importance of these factors on a regional or global basis.

Recovery time of wind resistance is much faster in soils with inherent aggregate stability, such as clays and gypsum. Recovery is also much faster in soils where physical crusts reform after rain events. Thus, coarse soils have less inherent resistance to wind erosion, and take longer to redevelop protection from wind erosion once disturbed. This suggests that, while biological soil crusts play an important role in preventing wind erosion in all soil types, the protection offered by biological soil crusts is especially critical in coarse soils.

References

Belnap J, Gardner JS (1993) Soil microstructure of the Colorado Plateau: the role of the cyanobacterium *Microcoleus vaginatus*. Great Basin Nat 53:40–47

Belnap J, Gillette DA (1997) Disturbance of biological soil crusts: impacts on potential wind erodibility of sandy desert soils in southeastern Utah. Land Degrad Dev 8:355–362

Belnap J, Gillette DA (1998) Vulnerability of desert biological soil crusts to wind erosion: the influence of crust development, soil texture, and disturbance. J Arid Environ 39:133–142

Chartes CJ (1992) Soil crusting in Australia. In: Summer ME, Stewart BA (eds) Soil crusting: chemical and physical processes. Lewis Publisher, Boca Raton, FL, pp 339–366

Danin A, Ganor E (1991) Trapping of airborne dust by mosses in the Negev Desert, Israel. Earth Surface Processes Landforms 16:153–162

Danin A, Yaalon DH (1982) Silt plus clay sedimentation and decalcification during plant succession in sands of the mediterranean coastal plain of Israel. Isrl J Earth Sci 31:101–109

Danin A, Bar-Or Y, Dor I, Yisraeli T (1989) The role of cyanobacteria in stabilization of sand dunes in southern Israel. Ecol Medit 15:55–64

Dulieu D, Gaston A, Darley J (1977) La dégradation des pâturages de la région N'Djamena (République du Tchad) en relation avec la présence de cyanophycées psammophiles – étude préliminaire. Rev Elev Méd Vét Pays Trop 30:181–190

Eldridge DJ, Green RSB (1994) Microbiotic soil crusts: a review of their roles in soil and ecological processes in the rangelands of Australia. Aust J Soil Res 32:389–415

Evans RD, Johansen JR (1999) Microbiotic crusts and ecosystem processes. Crit Rev Plant Sci 18:183–203

Garcia-Pichel F, Belnap J (1996) Microenvironments and microscale productivity of cyanobacterial desert crusts. J Phycol 32:774–782

Gillette DA, Adams J, Endo A, Smith D, Kihl R (1980) Threshold velocities for input of soil particles into the air by desert soils. J Geophys Res 85(C10):5621–5630

Goudie AS (1978) Dust storms and their geomorphological implications. J Arid Environ 1:291–310

Kovda V (1980) Land aridization and drought control. Westview Press, Boulder, CO

Leys JN (1990) Soil crusts, their effect on wind erosion. Soil Conservation Service of NSW Res Note 1/90

Leys JF, Eldridge DJ (1998) Influence of cryptogamic crust disturbance to wind erosion on sand and loam rangeland soils. Earth Surface Processes Landforms 23:963–974

Marticorena B, Bergametti G, Gillette D, Belnap J (1997) Factors controlling threshold friction velocity in semiarid and arid areas of the United States. J Geophys Res 102(D19):23,277–23,287

McKenna-Neuman C, Maxwell CD, Boulton JW (1996) Wind transport of sand surfaces crusted with photoautotrophic microorganisms. Catena 27:229–247

Musick HB (1998) Field monitoring of vegetation characteristics related to surface changes in the Yuma Desert, Arizona, and at the Jornada Experimental Range in the Chihuahuan Desert, New Mexico. US Geological Survey, Publication 1598-D

Offer ZY, Goossens D, Shachak M (1992) Aeolian deposition of nitrogen to sandy and loessial ecosystems in the Negev Desert. J Arid Environ 23:355–363

Pluis JLA (1994) Algal crust formation in the inland dune area, Laarder Wasmeer, The Netherlands. Vegetatio 113:41–51

Reynolds R, Belnap J, Reheis M, Mazza N (1998) Eolian dust on the Colorado Plateau – magnetic and geochemical evidence from sediment in potholes and biologic soil crust. In: Proc Conf on Dust Aerosols, Loess, Soils, and Global Change, Seattle, WA

Tsoar H, Møller JT (1986) The role of vegetation in the formation of linear sand dunes. In: Nickling WG (ed) Aeolian geomorphology. Allen and Unwin, Boston, MA, pp 75–95

Tsoar H, Pye K (1987) Dust transport and the question of desert loess formation. Sedimentology 34:139–153

Van den Ancker JAM, Jungerius PD, Mur LR (1985) The role of algae in the stabilization of coastal dune blow-outs. Earth Surface Processes Landforms 10:189–192

Verrecchia E, Yair A, Kidron GJ, Verrecchia K (1995) Physical properties of the psammophile cryptogamic crust and their consequences to the water regime of sandy soils, north-western Negev Desert, Israel. J Arid Environ 29:427–437

Webb RH, Wilshire HG (eds) (1983) Environmental effects of off-road vehicles: impacts and management in arid regions. Springer, Berlin Heidelberg New York

Williams JD, Dobrowolski JP, West NE, Gillette DA (1995) Microphytic crust influence on wind erosion. Trans Am Soc Agric Eng 38:131–137

27 Disturbance and Recovery of Biological Soil Crusts

J. Belnap and D. Eldridge

27.1 Introduction

Disturbance can profoundly affect the cover, species composition, and the physiological functioning of biological soil crusts. The disturbances we discuss include air pollution; exposure to oil, herbicides, and pesticides; invasion by annual exotic weeds; mechanical disturbances such as human and livestock trampling (see Chap. 29), off-road driving, mining, and hiking; and, briefly, wildfire (for extensive discussion, see Chap. 28). Studies on disturbance have generally been limited to the western US and Australia, with limited work done in China, Israel, South Africa, and Zimbabwe.

Methods of assessing impacts of, and recovery from, disturbance have been highly variable in the past. Generally, measurements have been limited to visual estimates of crust cover. However, Belnap (1993) showed that visual assessment can accurately assess only moss and lichen cover, and cannot be used to measure recovery of cyanobacterial biomass, soil stability, and/or physiological functioning of crustal organisms. In addition, some studies have only considered total crust cover but have not delimited the relative cover of cyanobacteria, mosses, and lichens. The relationships between total crust cover and impacts of disturbance can be weak, as cyanobacterial cover generally increases, while moss and lichen cover decreases, after disturbance. This often makes total crust cover a poor measure of the dynamics of soil-crust recovery. Differentiating between crustal components is also important because alteration of species composition can heavily influence ecological functioning of the crusts (Eldridge 1998).

Comparing recovery rates from different studies can be problematic, as factors known to control recovery rates (such as site stability and precipitation following disturbance) are often not reported. More importantly, severity of disturbance is seldom quantified. Studies generally report disturbance levels as "light", "moderate", or "heavy" without any definition of these categories; thus, what is "moderate" in one study may be considered "heavy" in another. As studies cover a large range of climatic zones, soil types, levels of

Ecological Studies, Vol. 150
J. Belnap and O.L. Lange (eds.) Biological Soil Crusts: Structure, Function, and Management
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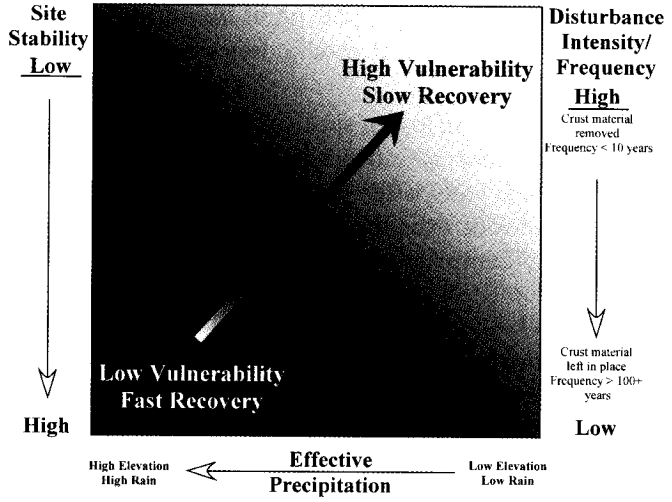
disturbance, and ways to calculate recovery, and because there has been no standard for measuring crust recovery, it is not surprising that recovery rates in the literature have ranged widely (2 years in cool deserts to over 3000 years in very dry deserts), and either show no pattern or often appear contradictory (Anderson et al. 1982; Callison et al. 1985; Jeffries and Klopatek 1987; Cole 1990; Belnap 1995,1996; Belnap and Warren 1998).

27.2 Disturbance Effects

The impact of a given disturbance depends on the soil, plant, and climate characteristics of the site, and the severity, frequency, timing, and type of the disturbance (Fig. 27.1). While most disturbances result in similar types of impacts, severity can vary widely. For instance, vehicles and trampling exert both compressional and shear forces; however, these forces are much greater for vehicles than trampling. In addition, vehicles often turn soils over and bury crustal organisms, while trampling tends to only compress the surface. Vehicle tracks often channel water and thus slow or prevent recovery (Webb and Wilshire 1983). Intensifying physical impacts (such as high-intensity, short-duration grazing) is deleterious to the cover and species richness of biological soil crusts (Johansen 1993). Disturbance that removes or kills crustal organisms results in greater impact and slower recovery than disturbance that leaves crushed crust material in place (see Sect. 27.3.3). As lichens and mosses are less tolerant of disturbance than cyanobacteria, frequent disturbance can maintain the biological soil crust at a low successional stage (e.g., cyanobacterially dominated; Harper and Marble 1988).

Timing of disturbance can affect the degree to which the cover and species richness of the crust is reduced. The intrinsic strength of soil varies with moisture content (Fig. 27.2). Soils with little tendency to form aggregates, such as sands, are more susceptible to compressional stresses when dry. Fine-textured soils or those with inorganic crusts are more vulnerable to compressional disturbance when wet (Webb and Wilshire 1983). Crust components are brittle when dry, and the connections they make between soil particles are easily crushed. Thus, compressional disturbances can severely affect the ability of crusts to stabilize soils, especially in dry sandy and silty soils. For instance, grazing in the early wet season (winter) has been shown to have less impact on crust cover and species composition than late winter or spring grazing. As crustal species are only metabolically active when wet and are brittle when dry, disturbance in dry seasons is more destructive, and organisms are less able to recover, than when disturbed in wet seasons (Harper and Marble 1988).



Factors Determining Site Stability

	Low Stability	High Stability
Soil Texture/Age	Coarse/Young	Fine/Old
Rock/Gravel Cover	Rolling	Embedded
Soil Depth	Deep	Shallow
Plant Spacing	Sparse	Dense

Fig. 27.1. Vulnerability and recoverability of crusts depends on gradients of site stability, effective precipitation, and disturbance regimes. *Top panel* Crusts at sites with the greatest stability (defined in *bottom panel*), greatest effective precipitation, and lowest disturbance frequency or intensity will be less impacted (*dark shading*) than sites with lower stability, less effective precipitation, and higher disturbance frequency or intensity (*light shading*). Similarly, recovery time is faster (*dark shading*) in areas of low vulnerability, and slower (*light shading*) where vulnerability is higher. *Bottom panel* Factors influencing site stability

Soil Moisture Content	Soil Texture: Sand	Clay	Silt
Frozen	Low	Low	Low
Wet	Medium-High	High	Low
Moist	Medium-High	Medium	Medium
Dry	Very High	Low	Very High

Fig. 27.2. Vulnerability of crusts to disturbance varies according to soil texture and moisture. Note crusts on sandy soils are more susceptible to disturbance when wet than when dry, while crusts on clay soils have the opposite response

27.2.1 Disturbance Effects on Species Composition of Biological Soil Crusts

Overall, disturbance generally results in loss of species diversity, biomass, and surface cover of cyanobacteria, lichens, and mosses. The more severe the disturbance, the greater the loss. Thus, after severe disturbance, the crust community with multiple species of cyanobacteria, lichens, and mosses is often simplified to a community dominated by one or a few species of cyanobacteria.

Air Pollution. A few studies have addressed the impact of air pollutants on soil lichens in desert environments. No differences have been found in species composition near pollution sources when compared to control sites. It is reasoned that lichens with thalli closely appressed to the soil surface, as found in most desert soil-crust lichens, are less susceptible to damage by air pollutants than lichens whose tissue is more exposed to air. In addition, most desert soils are very alkaline, and thus thought to buffer acidic pollutants (Nash and Sommerfeld 1981).

Oil Spills, Insecticides, and Herbicides. We know of no study that directly addresses the effects of oil, oil dispersants, insecticides, or herbicides on species composition of intact soil crusts. However, much work has been done on individual species of cyanobacteria, green algae, and mosses isolated from soil crusts. Tested species were differentially affected, both positively and negatively, depending on the compound and the species tested. Thus, exposure to these agents could either kill or potentially alter species composition of crusts (Metting 1981; Youtie et al. 1999).

Annual Plant Invasion. Invasion of exotic annual plants into perennial plant communities can impose a long-term threat to biological soil-crust communities because the crust-dominated interspace between perennial plants is often heavily invaded. Surveys in invaded communities show that rich perennial moss/lichen communities are quickly replaced with only a few species of annual mosses and cyanobacteria (Kaltenecker 1997; Belnap and Phillips 2000). The mechanism by which this shift occurs is not known, but probably results from increased plant material shading the soil surface, increased soil turnover by elevated rodent populations, and/or increased fire frequency.

Fire. The effects of fire are covered extensively in Chapter 28. In summary, the main effects of fire are loss of cover, biomass, and species diversity of soil crusts (Johansen et al. 1993). Damage to, and recovery of, soil crusts depends on the prefire composition and structure of the vascular plant community and distribution of fuel, fire intensity, and fire frequency. Hotter and more

frequent fires result in more damage to the crusts. Frequent fires prevent the recovery of lichens and mosses, resulting in crusts containing only a few species of cyanobacteria.

Mechanical Disturbance. Mechanical disturbance includes activities such as vehicle traffic (military and recreational), trampling by livestock (Chap. 29) and people, and land-clearing (such as mining). Such uses are intensifying exponentially in arid and semiarid areas of the world. Effects of mechanical disturbance are especially noticeable at sites with highly erodible soils and large topographic relief (Harper and Marble 1988).

Over 30 studies on four continents document that livestock grazing, vehicles (both recreational and military), and human trampling dramatically reduce lichen-moss cover and species richness of crusts. Resistance to disturbance generally decreases in the following order: cyanobacteria > gelatinous lichens > squamulose, crustose lichens; mosses > foliose lichens (reviewed in Harper and Marble 1988; West 1990; Johansen 1993; Eldridge and Greene 1994; Ladyman and Muldavin 1996). Cyanobacteria, being relatively mobile, are the most resistant to disturbance. Lichens use a combination of thallus structures, pigments, water storage capacities, tolerance of inundation, and/or an ability to fix atmospheric nitrogen (N) to increase resistance to disturbance. For example, Rogers and Lange (1971) showed that the lichens *Collema coccophorum* and *Heppia lutosa* (*H. despreauxii*) were the lichen species least affected by sheep trampling around a watering point. These lichens are able to fix atmospheric N, and to store greater amounts of water than phycolichens (Galun et al. 1982). In a comparison of species inside and outside a grazing exclosure, cover of most lichen species was significantly reduced with grazing (Table 27.1). In addition, most soil-surface disturbance compacts soils. Compaction influences soil water and nutrient-holding capacity, which can lead to changes in the species composition of soil-crust communities. These subtle compositional changes often occur before changes in cover are apparent (Eldridge 1996).

Burial. Disruption of crusts often destabilizes underlying soils, leaving adjacent crusts vulnerable to burial by wind and water-moved sediments. Large filamentous cyanobacteria can respond to limited burial by moving up to 5 mm every 24 h if wet. Mosses can also cope with limited burial (Fig. 15.2). However, when burial is too deep, these organisms will die. Burial often kills other photosynthetic components of the crust, including lichens, green algae, and smaller cyanobacteria (Campbell 1979), and thus generally results in a greatly simplified crustal community.

Table 27.1. Frequency (%) of lichens and a liverwort on loamy and sandy soils inside (ungrazed) and outside (grazed) exclosures at Koonamore Vegetation Reserve, South Australia in May 1972. Species extirpated by grazing (frequency = 0) were not evaluated statistically. Frequencies of all other species were significantly reduced with grazing ($p<0.10$). (After Crisp 1975)

Species	Type	Loamy soil		Sandy soil	
		Ungrazed	Grazed	Ungrazed	Grazed
Acarospora smaragdula	Crustose	2.2	0.4	0.2	0.0
Aspicilia calcarea	Crustose	27.4	18.0	11.3	2.1
Aspicilia calcarea	Fruticose	12.1	0.7	1.0	0.0
Collema coccophorum	Squamulose	46.7	40.2	36.4	17.4
Fulgensia subbracteata	Crustose	16.4	4.6	3.1	0.1
Psora decipiens	Squamulose	32.6	12.7	5.0	0.7
Eremastrella crystallifera	Squamulose	9.5	0.4	1.6	0.2
Toninia sedifolia	Squamulose	9.4	2.8	3.0	0.2
Riccia lamellosa	Liverwort	3.7	0.3	0.4	0.0

27.2.2 Disturbance Effects on Nutrient Inputs and Retention

Carbon inputs. Cyanobacterial crusts near coal-fired power plants have greater chlorophyll *a* per unit soil surface area than crusts away from the plant. This is partially a result of fertilization by nitrogen (N) and sulfur compounds from the effluents (Sheridan 1979; Belnap 1991). Photosynthesis-inhibiting herbicides show significant impact on *Nostoc* growth and N fixation (Gadkari 1988). In general, herbicides inhibit growth and reproduction in culture (Metting 1981). However, effects appear to be more pronounced in the laboratory than in the field, and may be transitory (Prasad et al. 1984).

Alteration in species composition of the crust will affect the total carbon (C) fixation of crusts, as lichens and mosses fix more C per unit soil surface area than cyanobacteria (Phillips and Belnap 1998). As much of the C fixed by crustal species is released into the surrounding soils (Lewin 1956), reduction in crust cover is expected to reduce soil C available for often carbon-limited microbial populations. This, in turn, may affect decomposition rates and soil-nutrient levels (Paul and Clark 1996).

Nitrogen Inputs. Effluents from power plants have been shown to decrease N fixation in *Collema* and *Microcoleus-Nostoc-Scytonema*-dominated crusts (Sheridan 1979; Belnap 1991). Atmospheric N deposition may offset reduced N inputs from crusts; alternatively, anthropogenic N deposition may aggravate N loss through increased ammonia volatilization and denitrification. In addition, biological soil crusts release ammonia in the soils, while anthropogenic N deposition contains large amounts of nitrate (F. Garcia-Pichel et al.,

unpubl. data). Microbial and vascular plant species differentially use ammonia and nitrate; thus, deposition of additional nitrates may alter ecosystem dynamics (Binkley et al. 1997).

Free-living or lichenized *Nostoc* show stimulation of N fixation at low concentrations or short exposure to arsenic, nickel, lead, palladium, and zinc. However, longer-term exposure to cadmium, lead, and zinc inhibit fixation (Henriksson and DaSilva 1978). The impact of insecticides, herbicides, phenolics, and oil compounds on N fixation is highly variable, as can be expected, given the vast array of these compounds. Exposure to crude oil and oil dispersants decreases N fixation in *Nostoc* (Marowitch et al. 1988). Nitrogen fixation is significantly inhibited in *Nostoc* by many insecticides, herbicides, and phenolic compounds tested (Megharaj et al. 1988; Bhunia et al. 1991).

Mechanical disturbance can result in large decreases in soil N through a combination of reduced input and elevated losses (Peterjohn and Schlesinger 1990; Evans and Belnap 1999). In all soils tested, disturbance by vehicles, human foot traffic, mountain bikes, and raking immediately reduces N input from crusts (25–40 % on silty soils; 76–89 % on sandy soils). Over time, nitrogenase activity can drop to 80–100 % of controls, due to subsequent death of buried material (Belnap et al. 1994; Belnap 1995, 1996).

Changes in species composition also affect N inputs, as cyanobacteria fix an order of magnitude less N than the equivalent soil surface area of cyanolichens such as *Collema* (see Chap. 16). Thus, the shift from a lichen crust to a cyanobacteria crust can result in less N entering the ecosystem, as has been shown in multiple studies. Jeffries et al. (1992) showed that heavy grazing reduced N fixation in sandy soils by 95 %. Terry and Burns (1987) measured a 64 % reduction of N fixation in a silty loam soil in burned areas, 85–94 % reduction in grazed areas, and 99 % reduction in a tilled area. *Collema* cover was reduced 50–80 % in grazed areas relative to adjacent ungrazed areas (Brotherson et al. 1983; Johansen and St. Clair 1986); thus, N inputs would be expected to be reduced accordingly. Evans and Belnap (1999) showed N fixation in an area released from grazing for 25 years was still 2.5 times less than an adjacent, never-grazed area due to a reduction in *Collema* cover.

Decreased N inputs from crusts can have long-term impacts on soil N levels (see Chap. 20). Jeffries (1989) found 50 % less N in grazed soils compared to adjacent ungrazed soils. Evans and Belnap (1999) found a 42 % decrease in soil N and 34 % decrease in plant tissue N when comparing a previously grazed to an adjacent ungrazed area. In the same area, stable N isotopes showed that both soil and plants in the grazed area contained less newly fixed N than the ungrazed area, and N mineralization potential decreased almost 80 % (Rimer and Evans 1997). This has large implications for ecosystems that are dependent on soil crusts for N inputs, such as found on the Colorado Plateau (Evans and Ehleringer 1993).

27.2.3 Disturbance and Vascular Plants

As discussed extensively in Chapter 21, crusts can affect vascular plant germination, survival, and nutrition. Lichen-moss crusts in areas with frost-heaving (as in cool and cold deserts) increase perennial vascular plant seed entrapment, germination, establishment, survival, biomass, and nutritional status (Belnap and Harper 1995). In these deserts, disturbance that flattens frost-heaved surfaces and/or eliminates mosses and lichens can have a negative effect on some or all of these characteristics. However, germination and survival of some exotic annual grasses can be enhanced with soil-crust disturbance.

In hot deserts, seed entrapment, biomass, and fecundity of annual plants is generally increased when smooth cyanobacterial crusts are disturbed (Prasse 1999), though there are some exceptions (Gutterman 1994). Disturbance of smooth cyanobacterial crusts enhances germination of some annual species, while decreasing germination of other annual species (Zaady et al. 1997). Rugose crusts in hot deserts have received little study. We found no work that addressed the effects of disturbance on seed entrapment in rugose crusts in hot deserts. Effects on germination in rugose crusts appear to be species-dependent. In contrast to smooth crusts, disturbance to hot-desert rugose crusts lessens survival and biomass of perennial plants (McIlvanie 1942; Crisp 1975).

Biological soil crusts have been shown to influence availability of many plant-essential nutrients, and the loss of crusts can result in less plant-available Mg, K, Fe, Ca, P, Mn, and S (Chap. 21). Spatial distribution of nutrients is also affected with disturbance, as lichen-moss crusts are more patchily distributed across the landscape than cyanobacterial crusts (Klopatek 1992).

27.2.4 Disturbance and Surface Albedo

Trampling of dark-crusted surfaces exposes underlying, lighter soils, thus increasing albedo (reflectance) by up to 50 % at most wavelengths measured. This represents an energy loss from the soil surface of approximately 40 W m^{-2}, and can reduce soil temperatures by up to 14 °C (Belnap 1995). Such changes in reflectance are especially evident with remote platforms, as can be seen in the Negev Desert, along the US-Mexico border and in Australia (see Chap. 31). Much of this difference is attributed to loss of biological soil crusts (Graetz and Tongway 1986). These large-scale changes in surface color may lead to changes in regional climate patterns (Sagan et al. 1979).

27.2.5 Disturbance and Soil Hydrology

The effect of crust disturbance on soil hydrology is very site-specific (see Part V). Water infiltration, runoff, and resultant soil moisture are influenced by soil surface roughness, soil texture, microtopography, surface albedo and temperature, vegetative cover (both vascular and nonvascular), and climatic conditions. All these factors can be altered when soil crusts are disturbed. In general, disturbance flattens rolling and pinnacled crusts, decreasing water infiltration and increasing runoff. Disturbance to smooth and rugose lichen- or cyanobacterial-crusted surfaces in hot deserts can increase overall infiltration rates (Greene et al. 1990; Eldridge et al. 2000). However, this increase in infiltration may negatively affect nearby vascular plants that depend on interspace runoff for survival in hyperarid regions (see Chaps. 21, 22). Alteration of soil structure as a result of soil compaction can also reduce infiltration rates. Available soil moisture is a complex interaction of many soil and plant characteristics, such as infiltration, soil moisture-holding capacity, albedo, and plant root density. Only three studies were found that addressed the combined effects of crusts on available soil moisture, with disparate results. Two studies found increased soil moisture under intact crusts, while the other found soil moisture increased under disturbed crusts (reviewed in Harper and Marble 1988; D. George, unpubl.).

27.2.6 Disturbance and Wind and Water Erosion

Compressional disturbance damages soil-stabilizing cyanobacterial sheath material both on the surface and at depth. The damage at depth is nonrepairable, as living cyanobacteria are not present to regenerate their sheaths. As more than 75 % of photosynthetic biomass and productivity are from organisms living in the top 3 mm of soils, disturbance that results in even small soil losses can dramatically reduce site fertility and further reduce soil-surface stability (Garcia-Pichel and Belnap 1996).

Water Erosion. Globally, studies consistently show that crust cover significantly decreases water erosion of both coarse-textured and fine-textured soils (see Chaps. 22–26). Continuous tracks have a greater impact than nonconnected disturbances (such as hoof prints) due to increased volume and velocity of water flow along the tracks (Webb and Wilshire 1983). Crushing of cyanobacterial connections between particles results in smaller, unconnected soil aggregates, which are then more easily moved by water. In addition, surfaces flattened by compressional disturbances are less able to reduce water velocity, thereby allowing movement of larger soil particles.

Wind Erosion. All studies of wind erosion indicate that disturbed soils are more susceptible to wind erosion than undisturbed soils. Soil particle movement is initiated at lower wind speeds when crusts are crushed or absent. Resistance to wind erosion varies with the development of biological soil crusts. Crusts with lichens and mosses, on both silt and sandy soils, have 2–130 times the resistance to soil erosion than less well-developed crusts or bare soil. Vehicle tracks result in greater damage than hoof prints on a given soil type. Decreased resistance of soils to wind erosion is directly associated with increased sediment movement. Experimental disturbances applied to crusts increased sediment production up to 35 times compared to adjacent undisturbed crusts (Belnap and Gillette 1997, 1998; J. Belnap, unpubl. data). Nearby soil crusts are often buried by blowing sediment, resulting in the death of photosynthetic organisms (for extensive discussion, see Chap. 25).

27.3 What Ecosystem Characteristics Confer Resistance to Soil-Surface Disturbance?

Biological soil crusts occur in many different habitats, ranging from subhumid areas that evolved with large herds of hooved animals (e.g., the Great Plains of the US, the Serengeti Plain in Africa, and the central Asian steppes) to arid and semiarid areas where limited food and water prehistorically supported few grazing animals. In habitats that evolved with high numbers of grazers, crusts are highly resistant to trampling, and grasses have characteristics that increase their tolerance of grazing (e.g., tillering, secondary compounds, and high tissue silica content). In contrast, most arid and semiarid desert areas have grasses with very low tolerance of grazing, and crusts intolerant of trampling, as even limited disturbance results in severe damage or extirpation of most crust species present (Martin 1975; Stebbins 1981; Mack and Thompson 1982; Belnap 1995, 1996).

Comparing regions with different evolutionary histories can aid in identifying ecosystem characteristics that support trampling-resistant crusts. For this purpose, crusts in four regions were compared: two regions that evolved with large hooved herds (central Asian steppes, Serengeti Plains); one region with herds of nonhooved animals (southeastern Australia) and one region without any large herds (Colorado Plateau). Crusts along rainfall gradients (200–400 mm) in these ecosystems were compared (J. Belnap, unpubl.). The cyanobacterium *Microcoleus* sp. was present on all soils, regardless of grazing pressure or precipitation. More-developed soil crusts showed increases in the biomass of *Microcoleus*, cover of the lichens *Collema* sp. and *Catapyrenium* sp. and biomass of surface-dwelling colonies of *Nostoc*

commune. Several factors were present when more-developed soil crusts were observed in areas of heavy grazing pressure: (1) soils were highly weathered, fine-textured to loamy (<50 % sand), moderately to highly calcareous, had high water-holding capacity, high bulk density (and thus did not churn easily), and some physical crusting. If sandy, soils were highly calcareous and very shallow; (2) sites had high effective rainfall, due to (a) greater total amount of rainfall, (b) cool-season rainfall, and/or (c) soils where water ponding occurred; (3) crust species present were those known to be resistant to trampling; (4) live and dead grass clumps were closely spaced (10 cm) or soils were very rocky, which protected much of the soil from direct hoof contact; and (5) animals did not stay in one area for more than a day, but kept moving through the landscape. Two important features were noted. First, high lichen diversity (>three species) was found only where grazing pressure was absent or minimal, or grazing pressure was due to animals without hooves (kangaroos). Secondly, where hooved animals were continually present, only cyanobacterial soil crusts were found.

27.4 Recovery of Biological Soil Crusts

27.4.1 Natural Recovery Rates

Recovery rates are dependent on many factors, including the type, severity, and extent of disturbance; structure of the vascular plant community; condition of adjoining substrates; availability of inoculation material; and climate during and after disturbance (Fig. 27.1). As discussed in the Introduction (Sect. 27.1), comparing reported recovery rates is problematic, as studies include a wide range of climatic zones, soil types, and levels of disturbance, and these factors are seldom quantified. Thus, most studies can only be used to define the general range of recovery rates.

All published estimates of crust recovery time are based on linear extrapolations of observed recovery rates (e.g., Anderson et al. 1982; Callison et al. 1985; Jeffries and Klopatek 1987; Cole 1990; Belnap 1995; Eldridge 1996). It is not known under what conditions this method is valid. On the Colorado Plateau, scalped plots were reassessed 2–5 and 10–14 years after disturbance. After 2–5 years, cyanobacterial cover was predicted to recover in 45–110 years, whereas it recovered within 14–34 years; thus, extrapolations based on 2–5 years greatly overestimated recovery time. Estimate of moss recovery after the first sample time was 400 years; after the second sampling time, it was 42 years. As with cyanobacteria, extrapolations based on early assessments overestimated recovery time. In contrast, *Collema* recovery after

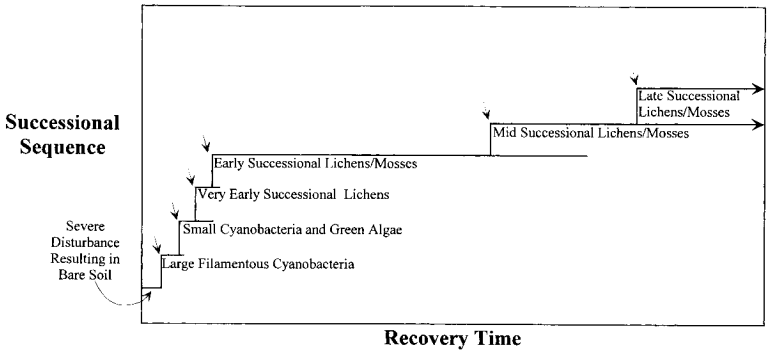
3 years was estimated at 85 years; after 14 years, estimates for full recovery were 50 years, a fairly close match. *Collema* recovery at another site was highly variable: after 2 years, recovery time was estimated at 487 years; after 11 years, estimates at plots within the site ranged from 40 to 766 years. Thus, original estimates were both under- and over-optimistic, depending on individual plot characteristics. Sites with more shade and less sandy soils were faster to recover than the original estimates predicted, while sunnier sites with sandier soils were slower to recover than the original estimates (J. Belnap, unpubl.).

Sequence of Species Appearance. Large filamentous cyanobacteria such as *Microcoleus* spp. are generally the first photosynthetic organisms to appear (Fig. 27.3), especially on unstable sandy soils (Ashley and Rushforth 1984; Belnap 1995). This is probably due to their mobility across soil surfaces and their ability to easily disperse via the air (Schlichting 1969). These large cyanobacteria are then followed by smaller cyanobacteria and green algae. Rarely, desert soils are slightly acidic, and here green algae can be the first to appear (Johansen 1993).

Lichens and mosses require stable soil surfaces for growth. This can be provided by a physical crust or by colonization of large, filamentous cyanobacteria. Once soils are stabilized, gelatinous N-fixing lichens (e.g., *Collema* spp.) are generally the first lichens to appear in disturbed areas, followed by early successional phycolichens and mosses (Johansen et al. 1984; Belnap 1993). Early-colonizing lichen species often disperse photobiont-containing tissue (e.g., isidia, soredia, thallus fragments, or algal-covered spores), as opposed to bare spores, thus precluding the need to find photobionts on site. In addition, cyanolichens may be the first to colonize alkine desert soils, as the cyanobiont *Nostoc* is much more numerous than any of the phycobionts required by phycolichens.

Colonization times vary widely for mid- and late-successional crust species, depending on site characteristics. Little is known about growth rates once colonization occurs. *Psora crenata* requires 55–100 years to regain full size in Australia (240 mm annual rain; Eldridge and Ferris 2000). Similar recovery times have been observed for *Diploschistes* in southern Idaho (R. Rosentreter, unpubl.).

Soil Texture. Soil texture influences recovery rates. In general, when climate and disturbance characteristics are similiar, recovery of all crust components is faster in fine-textured soils that form physical crusts compared to coarse-textured soils that do not form physical crusts when climate and disturbance characteristics are similar (Fig. 27.2; Table 27.2; reviewed in Harper and Marble 1988; Johansen 1993; Ladyman and Muldavin 1996). This is true both for disturbances severe enough to remove crusts and those crushed in place. Recovery of wind resistance is also more rapid in fine-textured soils, due to



Desert Type	Years to Recovery: Very Early Successional	Early Successional	Mid Successional	Late Successional
Lower Mojave (<1500 ,100 mm)	1200 →	3800		
High Mojave (1500 m, 200 mm)	200 →	800	NK	NK
Colorado Plateau (1500 m, 200 mm)	50 →	500	NK	NK
Northern Great Basin (1000 m, 350 mm)	20 →	25 →	60 →	125

Fig. 27.3. Colonization sequence and estimated recovery times for crustal species in the western US. *Top panel* Arrows indicate colonization events; *length of line* indicates relative time for recovery of each successional group. Species indicative of successional groups include: large filamentous Cyanobacteria: *Microcoleus* spp.; small Cyanobacteria: *Nostoc* spp.; very early-successional: *Collema* spp.; early-successional: *Catapyrenium* spp., *Pterygoneurum* spp.; mid-successional: *Psora* spp., *Fulgensia* spp. *Tortula* spp, *Bryum* spp.; late-successional: *Acarospora* spp., *Pannaria* spp. *Bottom panel* Relative recovery rates for different climates. Elevation and annual precipitation of characteristic regions are *in parentheses*. Reported estimates are averages, as sites show considerable variation in recovery times. Recovery rates of mid- and late-successional species are not known (*NK*) in drier deserts, where slow recovery times have precluded estimates. Estimates are based on published rates from studies cited in text

formation of chemical crusts after rainfall. While silty and sandy soils show a similar reduction in wind resistance to vehicle disturbance (83 and 74 %, respectively), silty soils show a 50 % recovery of wind resistance after a single large rain event. Sandy soils can take up to 10 years for a similar recovery (Belnap and Gillette 1997; J.E. Herrick et al., unpubl. data).

Climate Regimes. Crustal organisms are metabolically only active when wet; thus, recovery is faster in regions with greater effective precipitation (Figs. 27.1, 27.3; Table 27.2; Harper and Marble 1988; Johansen et al. 1993). Table 27.2 shows that cool-desert sites at higher latitudes (and thus lower annual temperatures) have quicker recovery for all crustal components than hot-desert sites with the same precipitation but higher annual temperatures, when disturbed similarly. Sites with lower annual precipitation and higher annual temperatures are the slowest to recover.

Table 27.2. Estimated recovery times of dated disturbances of known severity in the Mojave, Sonoran, Chihuahuan and Colorado Plateau deserts of the western US (J. Belnap et al., unpubl.)

Desert type	Disturbance severity	Soil texture	Annual rainfall range (mm)	Elevation range (m)	Years since disturbance	Estimated recovery times (years)				No. of lichen species	
						Cyanobacteria	*Collema*	Other lichens	Moss	Disturbed	Control
Coastal	Removed	Fine	179	100	5		>20–200	>200		1	5
Cool	Removed	Coarse	220–230	1500–1800	10–14	14–34	50–400	>200–875	82–>766	1	4–5
		Fine	230	1600	14	9	>20–240	>200	>140	1	3–5
	Crushed	Coarse	220–230	1500–1800	6–13	7-14	10–71		26–39	1	1–4
		Fine	215	1550	2	2	6	3	4	1	2
Hot	Removed	Coarse	119–230	271–1730	50–80	<81–100	217–1250	580–3700	<81	2	2–7
	Crushed	Coarse	74–248	500–950	2–20	3	10–90	>9		1	1–2
		Fine	248–256	500–1300	2	2–3	4–15	>4		1	2

The "<" indicates that the component was fully recovered when the site was sampled. If a crust component was observed in the control plots but not found in the disturbed plots, a value of 0.01 % relative cover was used to calculate a minimum recovery time; these calculated values are preceeded by a ">". The last two columns indicate the number of lichen species present in the disturbed areas relative to the number of species in the control areas.

Type, Frequency, Severity, and Size of Disturbance. We found no work that addressed recovery rates of soil-crust lichens or cyanobacteria from air pollution. Recovery from fire is specifically covered in Chapter 28. In general, crusts are highly susceptible to damage by hot fires; thus, recovery will depend on the size and intensity of fires. As noted previously in Section 27.2 above, most compressional disturbances have similar types of impacts. However, severity of mechanical disturbance can vary widely with disturbance type. Thus, on similar soils, vehicle tracks generally have longer recovery times than disturbances that do not churn the soil or make continuous tracks (Wilshire 1983; Belnap 1996). Repeated disturbance will generally keep crusts at an early-successional stage (e.g., cyanobacteria-dominated) by preventing colonization of lichens or mosses (Fig. 27.3; Belnap 1996).

Severity of disturbance can control recovery rates. In the western US, recovery of adjacent sites within a given soil and climate type is generally faster when disturbance is not severe enough to remove crustal material (Table 27.2). In addition, because recolonization of disturbances occurs mostly by material washing or blowing in from adjacent, less-disturbed areas, the rate of lichen recovery is much slower in areas with higher internal surface areas relative to perimeter area (Eldridge and Ferris 2000; J. Belnap, unpubl. data).

Condition of Adjoining Substrate. In general, recovery is slower if soils adjacent to disturbed areas are destabilized. Detached sediment can both bury adjacent crusts and/or provide material for sandblasting nearby surfaces, thus increasing wind erosion rates and reducing recovery rates (Belnap 1995; McKenna-Neuman et al. 1996; Leys and Eldridge 1998).

Vascular Plant Structure. Crusts recover more quickly under shrub canopies than adjacent plant interspaces. This is probably due to greater soil moisture and fertility under shrub canopies. In the Mojave Desert, lichen recovery 50 years after total removal was 36 % complete under shrub canopies and only 4 % complete in the shrub interspaces (Belnap and Warren 1998). A similar pattern was seen in plots on the Colorado Plateau, where lichen recovery was two to three times faster under shrubs than in adjacent interspaces (J. Belnap, unpubl. data).

The growth of biological soil crusts and vascular plants can be an interactive process (Danin et al. 1989). Eldridge and Greene (1994) present a conceptual model in which crust development at sites is strongly linked to the restoration of vital soil processes. As primary colonizers of recovering sites, biological soil crusts enhance microsite fertility and provide safe sites for seeds (see Chap. 21). In turn, established vascular plants help stabilize soils, provide shade, and reduce wind speeds at the soil surface, providing conditions conducive to further diversification of the biological soil crusts (Wood et al. 1982; Danin et al. 1989).

Nitrogen and Carbon Fixation. Recovery of N and C fixation rates after disturbance is dependent on the species composition, biomass, and physical structure of the crust. Thus, recovery of N fixation is dependent on recovery rates of cyanobacteria and cyanolichens (see Sect. 27.3.1). Nitrogen fixation in crusts can require anaerobic microzones in the soils, which may be dependent on the buildup of cyanobacterial biomass (Belnap 1996). Recovery of C fixation is mainly dependent on moss and lichen cover. As recovery is faster with higher available moisture, N and C fixation rates are expected to recover faster in cool deserts than in hot deserts, other factors being equal.

Lichen cover may not fully recover after disturbance, as conditions which allowed its initial establishment may no longer be present. For example, 30 years after cessation of grazing, soil space previously occupied by lichens was occupied by mosses in SE Utah, and thus lichens are not necessarily expected to return (Evans and Belnap 1999). Consequently, soil N, plant N, and N fixation are still lower in the previously grazed areas when compared to an ungrazed area. Reduced N inputs are expected as long as lichen recovery does not occur.

Surface Albedo. Restoration of normal surface albedos and temperatures will depend on the restoration of predisturbance cover of cyanobacteria, lichens, and mosses. While cyanobacteria form a darkish matrix in which other components are embedded, most mosses and lichens are much darker (Belnap 1993). Consequently, recovery of surface albedos will be limited by factors that control recovery of lichens and mosses.

27.4.2 Enhancing Recovery with Inoculation

Inoculants can be used to speed soil-crust recovery (Lewin 1977; Tiedemann et al. 1980; Ashley and Rushforth 1984; St. Clair et al. 1986; Belnap 1993; Buttars et al. 1998). Applied inoculants have ranged from commercially available preparations (Lewin 1977) to laboratory-prepared material (Buttars et al. 1998) to material transported from nearby areas (Belnap 1993). In all cases, inoculation enhanced recovery rates of cyanobacterial and lichen biomass and species diversity. For example, 3 years after scalping and inoculating plots with nearby crumbled crusts (10:1 removed to inoculated material), cyanobacterial biomass in inoculated plots was almost twice that of uninoculated plots (0.14 vs. 0.077), lichen cover was 43.3 versus 3.6 % (respectively) and lichen species were 4.3 versus 1.8 species (respectively). The entire surface area of the inoculated plots appeared covered by cyanobacteria, and pedicellation had begun (Belnap 1993). In a laboratory study, Buttars et al. (1998) isolated, cultured, and then made alginate pellets of *Microcoleus vaginatus.* These pellets were then placed on petri dishes. After 3 months, inoculated dishes had higher filament density and N fixation rates.

27.5 Conclusions

Disturbance can directly and indirectly affect many aspects of the structure and function of biological crust communities. Moderate to severe disturbance generally results in the simplification of the crust community from one containing multiple species of cyanobacteria, lichens, and mosses to a community consisting of only a few species of cyanobacteria. This alteration of species composition reduces C and N inputs from the crusts. Disturbance is also generally accompanied by loss of surface roughness, which affects local hydrologic regimes and vascular plant seed entrapment. Compressional disturbances break the cyanobacterial connections to soil particles, thus increasing vulnerability of the underlying soils to wind and water erosion. As fine soil particles are preferentially lost, increased erosion reduces site fertility. Disturbance also increases soil albedo and reduces soil temperatures. This, in turn, affects the soil microbial and vascular plant communities.

Some generalizations can be made regarding recovery rates for crusts. Recovery rates are faster for infrequent or minor disturbances where crustal material is crushed in place compared to severe or repeated disturbances that result in complete removal of crustal material. Recovery is faster on fine-textured compared to sandy soils. Recovery is also faster in regions with greater effective precipitation. Recovery is different among crust functional groups, with rates increasing in the following order: cyanobacteria > gelatinous cyanolichens > annual mosses, perennial phycolichens with dispersal mechanisms that avoid early growth stages > perennial phycolichens and mosses without specialized dispersal mechanisms. Recovery of physiological functioning is dependent on the recovery of specific species, e.g., N inputs are dependent on recovery rates for cyanobacteria and cyanolichens. Complete recovery to predisturbance states may not be possible, due to altered edaphic or climate regimes, or lack of source material for colonization.

Acknowledgments. We thank Sue Phillips, Tonya Troxler, Roger Rosentreter, Julie Kaltenecker, and Michelle Schmid for useful comments and graphics.

References

Anderson DC, Harper KT, Rushforth SR (1982) Recovery of cryptogamic soil crusts from grazing on Utah winter ranges. J Range Manage 35:355–359

Ashley J, Rushforth SR (1984) Growth of soil algae on top soil and processed oil shale from the Uintah Basin, Utah, USA. Reclam Reveg Res 3:49–63

Belnap J (1991) Effects of wet and dry pollutants on the physiology and elemental accumulation of cryptogamic crusts and selected lichens of the Colorado Plateau. National Park Service, Air Quality Division Final Report, Denver, CO

Belnap J (1993) Recovery rates of cryptobiotic crusts: inoculant use and assessment methods. Great Basin Nat 53:89–95

Belnap J (1995) Surface disturbances: their role in accelerating desertification. Environ Mon Assess 37:39–57

Belnap J (1996) Soil surface disturbances in cold deserts: effects on nitrogenase activity in cyanobacterial-lichen soil crusts. Biol Fertil Soils 23:362–367

Belnap J, Gillette DA (1997) Disturbance of biological soil crusts: impacts on potential wind erodibility of sandy desert soils in southeastern Utah. Land Degrad Dev 8:355–362

Belnap J, Gillette DA (1998) Vulnerability of desert biological soil crusts to wind erosion: the influence of crust development, soil texture, and disturbance. J Arid Environ 39: 133–142

Belnap J, Harper KT (1995) Influence of cryptobiotic soil crusts on elemental content of tissue of two desert seed plants. Arid Soil Res Rehabil 9:107–115

Belnap J, Phillips SL (2000) Consequences of an annual plant invasion on soil food webs in an undisturbed semi-arid grassland. Ecol Appl (in press)

Belnap J, Warren S (1998) Measuring restoration success: a lesson from Patton's tank tracks. Ecol Bull 79:33

Belnap J, Harper KT, Warren SD (1994) Surface disturbance of cryptobiotic soil crusts: nitrogenase activity, chlorophyll content, and chlorophyll degradation. Arid Soil Res Rehabil 8:1–8

Bhunia AK, Basu NK, Roy D, Chakrabarti A, Banerjee SK (1991) Growth, chlorophyll *a* content, nitrogen-fixing ability, and certain metabolic activities of *Nostoc muscorum*: effect of methylparathion and benthiocarb. Bull Environ Contam Toxicol 47:43–50

Binkley D, Giardiana C, Dockersmith I, Morse K, Scruggs M, Tonnessen K (1997) Status of air quality and related values in Class I National Parks and Monuments of the Colorado Plateau. NPS-AQ D-358

Brotherson JD, Rushforth SR, Johansen JR (1983) Effects of long-term grazing on cryptogam crust cover in Navajo National Monument, Arizona. J Range Manage 36:579–581

Buttars SM, St Clair LL, Johansen JR, Sray JC, Payne MC, Webb BL, Terry RE, Pendleton BK, Warren SD (1998) Pelletized cyanobacterial soil amendments: laboratory testing for survival, escapability, and nitrogen fixation. Arid Soil Res Rehabil 12:165–178

Callison J, Brotherson JD, Bowns JE (1985) The effects of fire on the blackbrush (*Coleogyne ramosissima*) community of southwestern Utah. J Range Manage 38: 535–538

Campbell SE (1979) Soil stabilization by a prokaryotic desert crust: implications for Precambrian land biota. Origins Life 9:335–348

Cole DN (1990) Trampling disturbance and recovery of cryptogamic soil crusts in Grand Canyon National Park. Great Basin Nat 50:321–325

Crisp MD (1975) Long-term change in arid-zone vegetation at Koonamore, South Australia. PhD Dissertation, University of Adelaide, Adelaide

Danin A, Bar-Or Y, Dor I, Yisraeli T (1989) The role of cyanobacteria in stabilization of sand dunes in southern Israel. Ecol Mediterr 15:55–64

Eldridge DJ (1996) Distribution and floristics of terricolous lichens in soil crusts in arid and semi-arid New South Wales, Australia. Aust J Bot 44:581–599

Eldridge DJ (1998) Trampling of microphytic crusts on calcareous soils and its impact on erosion under rain-impacted flow. Catena 33:221–239

Eldridge DJ, Ferris J (2000) Recovery of populations of the soil lichen *Psora crenata* after disturbance in arid South Australia. Rangel J 21:194–198

Eldridge DJ, Greene RSB (1994) Microbiotic soil crusts: a review of their roles in soil and ecological processes in the rangelands of Australia. Aust J Soil Res 389–415

Eldridge DJ, Koen TB (1998) Cover and floristics of microphytic soil crusts in relation to indices of landscape health. Plant Ecol 137:101–114

Eldridge DJ, Zaady E, Shachak M (2000) Infiltration through three contrasting biological soil crusts in patterned landscapes in the Negev, Israel. Catena 40:323–336

Evans RD, Belnap J (1999) Long-term consequences of disturbance on nitrogen dynamics in an arid ecosystem. Ecology 80:150–160

Evans RD, Ehleringer JR (1993) A break in the nitrogen cycle in arid lands? Evidence from $\delta^{15}N$ of soils. Oecologia 94:314–317

Gadkari D (1988) Effect of some photosynthesis-inhibiting herbicides on growth and nitrogenase activity of a new isolate of cyanobacteria, *Nostoc* G3. J Basic Microb 28:419–426

Galun M, Burbrick P, Garty J (1982) Structural and metabolic diversity of two desert lichen populations. J Hattori Bot Lab 53:321–324

Garcia-Pichel F, Belnap J (1996) Microenvironments and microscale productivity of cyanobacterial desert crusts. J Phycol 32:774–782

Graetz RD, Tongway DJ (1986) Influence of grazing management on vegetation, soil structure and nutrient distribution and the infiltration of applied rainfall in a semi-arid chenopod shrubland. Aust J Ecol 11:347–360

Greene RSB, Chartes CJ, Hodgkinson KC (1990) The effects of fire on the soil in a degraded semi-arid woodland. I. Cryptogam cover and physical and micromorphological properties. Aust J Soil Res 28:755–777

Gutterman Y (1994) Strategies of seed dispersal and germination in plants inhabiting deserts. Bot Rev 60:373–425

Harper KT, Marble JR (1988) A role for nonvascular plants in management of arid and semi-arid rangelands. In: Tueller PT (ed) Vegetation science applications for rangeland analysis and management. Kluwer Academic Publishers, Dordrecht, pp 136–169

Henriksson LE, DaSilva EJ (1978) Effects of some inorganic elements on nitrogen-fixation in blue-green algae and some ecological aspects of pollution. Z Allg Mikrobiol 18:487–494

Jeffries DL (1989) The vegetation, soil, and cryptogamic crusts of blackbrush communities in the Kapairowits Basin. PhD Dissertation, Dept Botany, Arizona State University, Tempe, AZ

Jeffries DL, Klopatek JM (1987) Effects of grazing on the vegetation of the blackbrush association. J Range Manage 40:390

Jeffries DL, Klopatek JM, Link SO, Bolton H Jr (1992) Acetylene reduction by cryptogamic crusts from a blackbrush community as related to resaturation and dehydration. Soil Biol Biochem 24:1101–1105

Johansen JR (1993) Cryptogamic crusts of semiarid and arid lands of North America. J Phycol 29:140–147

Johansen JR, St Clair LL (1986) Cryptogamic soil crusts: recovery from grazing near Camp Floyd State Park, Utah, USA. Great Basin Nat 46:632–640

Johansen JR, St Clair LL, Webb, BL, Nebeker GT (1984) Recovery patterns of cryptogamic soil crusts in desert rangelands following fire disturbance. Bryologist 87: 238–243

Johansen JR, Ashley J, Rayburn WR (1993) Effects of rangefire on soil algal crusts in semiarid shrub-steppe of the lower Columbia Basin and their subsequent recovery. Great Basin Nat 53:73–88

Kaltenecker JH (1997) The recovery of microbiotic crusts following post-fire rehabilitation on rangelands of the western Snake River Plain. MS Thesis, Boise State University, Boise

Klopatek JM (1992) Cryptogamic crusts as potential indicators of disturbance in semi-arid landscapes. In: McKenzie DH, Hyatt DE, McDonald VJ (eds) Ecological indicators, vol. 1. Elsevier, Brisbane, UK, pp 773–786

Ladyman JAR, Muldavin E (1996) Terrestrial cryptogams of pinyon-juniper woodlands in the southwestern United States: a review. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report, RM-GTR-280

Lewin RA (1956) Extracellular polysaccharides of green algae. Can J Microbiol 2:665–673

Lewin RA (1977) The use of algae as soil conditioners. Scripps Inst Oceanogr Trans 3:33–35

Leys JF, Eldridge DJ (1998) Influence of cryptogamic crust disturbances to wind erosion on sand and loam rangeland soils. Earth Surface Processes Landforms 23:963–974

Mack RN, Thompson JN (1982) Evolution in steppe with few large, hooved mammals. Am Nat 119:757–773

Martin PS (1975) Vanishings, and future of the prairie. Geosci Man 10:39–49

Marowitch J, Dale MRT, Hoddinott J (1988) The effect of crude oil and oil spill chemicals on nitrogen fixation in the cyanobacteria *Nostoc* sp. Environ Pollut 51:75–83

McIlvanie SK (1942) Grass seedling establishment and productivity-overgrazed vs. protected range soils. Ecology 23:228–231

McKenna-Neuman C, Maxwell CD, Boulton JW (1996) Wind transport of sand surfaces crusted with photoautotrophic microorganisms. Catena 27:229–247

Megharaj M, Venkateswarlu K, Rao AS (1988) Effect of insecticides and phenolics on nitrogen fixation by *Nostoc linckia*. Bull Environ Contam Toxicol 41:277–281

Metting FB (1981) The systematics and ecology of soil algae. Bot Rev 47:195–312

Nash TH III, Sommerfeld MR (1981) Elemental concentrations in lichens in the area of the Four Corners Power Plant, New Mexico. Environ Exp Bot 21:153–162

Paul EA, Clark FE (1996) Soil microbiology and biochemistry. Academic Press, London

Peterjohn WT, Schlesinger WH (1990) Nitrogen loss from deserts in the southwestern United States. Biogeochemistry 10:67–79

Phillips SL, Belnap J (1998) Shifting carbon dynamics due to the effects of *Bromus tectorum* invasion on biological soil crusts. Ecol Bull 79:205

Prasad RBV, Dhanaraj PS, Narayana Rao VVS (1984) Effects of insecticides on soil microorganisms. In: Lal R (ed) Insecticide microbiology. Springer, Berlin Heidelberg New York, pp 169–202

Prasse R (1999) Experimentelle Untersuchungen an Gefäßpflanzenpopulationen auf verschiedenen Geländeoberflächen in einem Sandwüstengebiet (Experimental studies with populations of vascular plants on different soil surfaces in a sand desert area). Universitätsverlag Rasch, Osnabrück, Germany

Rimer RL, RD Evans (1997) The impact of disturbance and an invasive grass species on N mineralization in a cold-desert system (abs). Ecol Bull 78:303

Rogers RW, Lange RT (1971) Lichen populations on arid soil crusts around sheep watering places in South Australia. Oikos 22:93–100

Sagan C, Toon OB, Pollack JB (1979) Anthropogenic albedo changes and the earth's climate. Science 206:1363–1368

Schlichting HE Jr (1969) The importance of airborne algae and protozoa. J Air Pollut Control Assoc 19:946–951

Sheridan RP (1979) Impact of emissions from coal-fired electricity generating facilities on N_2-fixing lichens. Bryologist 82:54–58

St Clair LL, Johansen JR, Webb BL (1986) Rapid stabilization of fire-disturbed sites using a soil crust slurry: inoculation studies. Reclam Reveg Res 4:261–269

Stebbins GL (1981) Coevolution of grasses and herbivores. Ann Mo Bot Gard 68:75–86

Terry RE, Burns SJ (1987) Nitrogen fixation in cryptogamic soil crusts as affected by disturbance. US Dept of Agriculture, Forest Service, Intermountain Research Station, Reno, NV, pp 369–372

Tiedemann AR, Lopushinsky W, Larsen HJ Jr (1980) Plant and soil responses to a commercial blue-green algae inoculant. Soil Biol Biochem 12:471–475

Webb RH, Wilshire HG (1983) Environmental effects of off-road vehicles: impacts and management in arid regions. Springer Series on Environmental Management. Springer, Berlin Heidelberg New York

West NE (1990) Structure and function of microphytic soil crusts in wildland ecosystems of arid to semi-arid regions. Adv Ecol Res 20:179–223

Wilshire HG (1983) The impact of vehicles on desert soil stabilizers. In: Webb RH, Wilshire HG (eds) Environmental effects of off-road vehicles. Springer, Berlin Heidelberg New York, pp 31–50

Wood MK, Blackburn WH, Eckert RE Jr, Peterson FF (1982) Influence of crusting soil surfaces on emergence and establishment of crested wheatgrass, squirreltail, thurber needlegrass, and fourwing saltbush. J Range Manage 35:282–287

Youtie B, Ponzetti J, Salzer D (1999) Fire and herbicides for exotic annual grass control: effects of native plants and microbiotic soil organisms. In: Eldridge D, Freudenberger D (eds) People and rangelands: building the future. Proc 6th Int Rangelands Congress, Townsville, Australia, vol 2, pp 590–591

Zaady E, Gutterman Y, Boeken B (1997) The germination of mucilaginous seeds of *Plantago coronopus*, *Reboudia pinnata*, and *Carrichtera annua* on cyanobacterial soil crusts from the Negev Desert. Plant Soil 190:247–252

Fire and Changes in Creosote Bush Scrub of the Western Sonoran Desert, California

DAVID E. BROWN[1]
and
RICHARD A. MINNICH
Geography Program, Department of Earth Sciences, University of California, Riverside, Riverside, California 92521

ABSTRACT: Seven years of above normal precipitation between 1976 and 1983 encouraged heavy growth of native annuals and exotic grasses in the western Sonoran Desert. Unprecedented fires in creosote bush scrub started mostly after 1978. Analysis of several burns near Palm Springs revealed that most shrubs, including *Larrrea tridentata, Ambrosia dumosa* and *Opuntia* spp., are poorly adapted to relatively low intensity fires as evidenced by limited sprouting and reproduction. These shrubs were replaced by open stands of *Encelia farinosa*, native ephemerals, and European exotics, mostly *Bromus rubens* and *Schismus barbatus*. The rapid selective thinning of creosote bush scrub species suggests that the modern biogeography of this ecosystem may be controlled, in part, by recurrent burning.

INTRODUCTION

Fires are infrequent in the Sonoran Desert owing to limited biomass, wide spacing between shrubs and sparse ground cover (Humphrey, 1949, 1962). Recent studies in Arizona (Rogers and Steele, 1980) and California (Tratz and Vogl, 1977: Tratz, 1978; O'Leary and Minnich, 1981) indicate that many desert perennials are poorly adapted to burning. Successional studies in creosote bush scrub reveal postdisturbance recolonization by long-lived species is very slow initially and may require hundreds of years (Vasek, 1980, 1983). Thus rare fires may have long-term impact on the structure and composition of this community.

Heavy growth of native and exotic annual vegetation promoted by extraordinarily heavy precipitation between 1976 and 1983 resulted in unprecedented fires in creosote bush scrub vegetation along the western margins of the Mojave and Sonoran deserts of southern California. This study documents fire and early postfire succession in creosote bush scrub in several burns near Palm Springs, and it evaluates the stability and biogeography of this ecosystem in relation to recurrent fire.

STUDY AREA

Four sites on Quaternary alluvial fans descending from the E scarp of the San Jacinto Mountains at the end of the Coachella Valley near Palm Springs, California, were chosen for study (Fig. 1). Coarse-textured soils are well-drained, moderately alkaline with a minimum of organic matter (Fraser, 1931; Proctor, 1968; Knecht, 1980).

The climate of the Coachella Valley is extremely arid owing to its subtropical latitude and to rain shadows of the San Jacinto Mountains (Bailey, 1966). Average annual rainfall at Palm Springs, mostly from winter cyclonic storms, is 138 mm (Table 1). Summers are hot and dry, although tropical moisture from the equatorial Pacific produce occasional thunderstorms, mostly over the nearby mountains.

VEGETATION

Most of the Sonoran Desert is covered with creosote bush scrub consisting of scattered low shrubs less than 2 m. Representative growth forms include evergreen

[1]Present Address: Ultrasystems, Inc. Environmental Systems Division, 16845 Von Karman Avenue, Irvine, California 92714.

sclerophyllous and deciduous shrubs, subligneous subshrubs, leaf and stem succulents, and annual herbs (Johnson, 1974; Burk, 1977). Bajadas and adjacent mountainsides in the Coachella Valley are covered by *Larrea tridentata*, *Encelia farinosa*, *Hilaria rigida*, *Enchinocereus engelmannii*, and *Krameria grayi*. Vegetation on the plains and lower bajadas, including the study sites, is dominated by *L. tridentata*, *Ambrosia dumosa* and *E. farinosa*, which may form 60-100% of total vegetation cover (McHargue, 1973; Shreve and Wiggins, 1964). *Cercidium floridum*, *Olynea tesota*, *Dalea spinosa*, *Beloperone californica* and *Hyptis emoryi* are common along washes. Succulents such as *Ferocactus acanthodes*, *Echinocereus engelmannii*, *Opuntia basilaris*, *O. bigelovii* and *O. echinocarpa* reach maximum densities on sandy hillsides and bajadas with rocky, gravelly, or sandy substrates (McHargue, 1973).

FIRE HISTORY

Until the last decade, burning was almost unknown in the area (Fig. 1). Two large fires in 1911 and 1945 burned chaparral and mixed evergreen forests above 1200 m. A 3600-ha fire on the N slope of Mt. San Jacinto in 1973 spread into a small area of creosote bush scrub (O'Leary and Minnich, 1981). Two rare Mexican west coast tropical storms (September 1976, August 1977), followed by abnormally stormy winters from 1977-1978 to 1979-1980 and 1982-1983, caused sustained above-normal precipitation

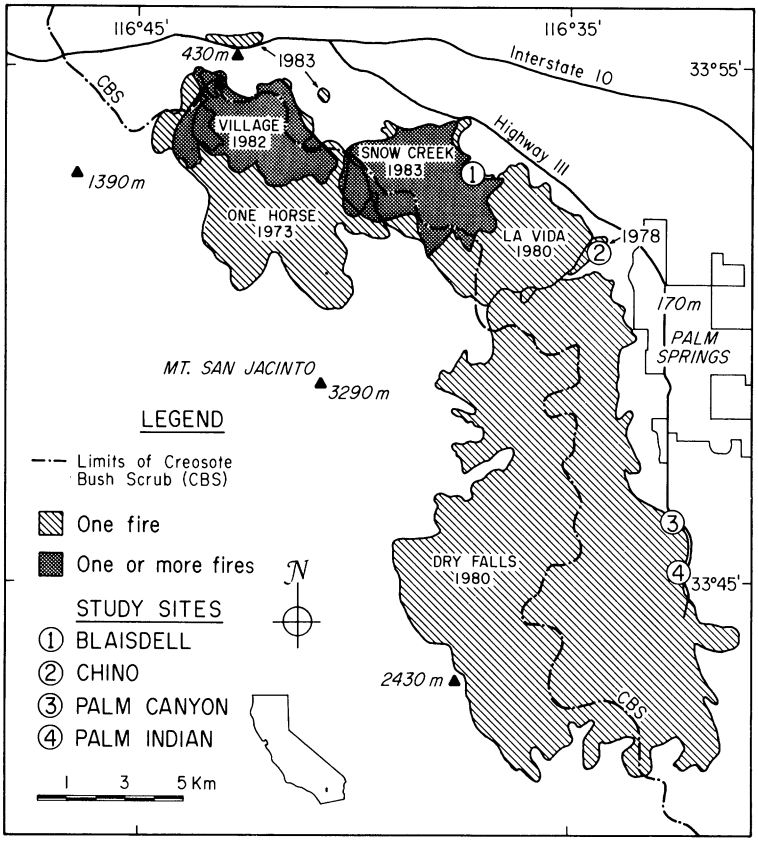


Fig. 1.—The study sites and fire perimeters. Limits of cresote bush scrub are interpreted from 1:30,000 scale aerial photography (1971) on file at the Department of Earth Sciences, University of California, Riverside

(Table 1) which encouraged heavy growth of shrubs and herbaceous understory. Beginning in 1978, a series of fires spread through dried herbaceous fuels into extensive areas of creosote bush scrub, including the Chino Canyon fan (500 ha, 1978), Blaisdell and Chino canyons (2800 ha, 1980), and the E scarp and alluvial fans below 1300 m from Chino Canyon S to Palm Canyon (6000 ha, 1980). A 1200-ha burn in 1982 overlapped large areas burned in 1973 near Snow Creek. In 1983, the first of three fires reburned portions of Snow Creek and Blaisdell Canyon. Two smaller fires also occurred along Snow Creek road and Interstate 10.

The fires in creosote bush scrub characteristically spread during periods when ambient temperatures averaged 35-40 C and relative humidity ranged from 10-25%. High winds (10-20 ms^{-1}) were caused by the typical spring and early summer gravity acceleration of descending coastal marine air spilling through San Gorgonio Pass. Upcanyon winds and nocturnal air drainage promoted fire spread on the eastern face of Mt. San Jacinto. The flames reduced the herb layer to a low stubble, indicative of fast-moving, low-intensity fires.

SITE SELECTION AND METHODS

Four sites were located on relatively homogeneous terrain (*i.e.*, avoiding large washes or rock outcrops) at the fire boundaries on the Chino, Blaisdell and Palm Canyon alluvial fans in order to compare burned vegetation with adjacent unburned stands (Fig. 1). The areas were surveyed between 25 April and 27 May 1983, when desert annuals were declining and perennials were in full growth or flower.

Perennial and annual plants were analyzed separately, with major emphasis placed on perennial cover and density. In unburned transects, the vegetation sampled is assumed to represent the prefire state of burned areas. In each site, two 100-m parallel transects were employed in burned and unburned areas (200 m for each). Both belt and line methods of sampling were used along each 100-m transect (Mueller-Dombois, 1974). The line intercept method was used to obtain percent cover (intercept distance) and density of perennial species (*cf.* Canfield, 1942). Each plant along the intercept was measured, identified and counted. Seedlings on each intercept were counted as part of total perennial cover, and were also noted separately. Belt transects (100 m x 1 m) were used to determine seedling density. Seedlings were counted and time of establishment was assigned as first postfire growing season (older plants > 5 cm height) or later growing season (< 5 cm). A 1-m-sq area was located at the end point of each transect to estimate herbaceous cover and floristic composition.

In transects within the burns, surviving plants, sprouting behavior and mortality (fire-killed snags) were recorded. Fire damage was estimated by qualitatively ranking plants as burned, scorched or green. Burned plants showed pyrolysis of foliage and fine

TABLE 1.—Annual precipitation at Palm Springs (source: California 1984)

Season	Total (mm)	Percent of normal
1889-1983 Mean	138	
1976-1977	174	126
1977-1978	289	209
1978-1979	188	136
1979-1980	412	299
1980-1981	64	46
1981-1982	98	71
1982-1983	222	161

stems, leaving a stump or main stems. Scorched plants retained all or most branches and dried foliage. Green plants retained living foliage or escaped fire entirely. In belt transects, plant snags were counted and ranked for fire damage and recovery. Seedlings were counted in each meter and assigned establishment dates as in unburned areas.

RESULTS

The vegetation was sampled 3 growing seasons after burns at Blaisdell, Palm Canyon and Palm Indian sites and after 5-growing seasons at the Chino site. However, data for Chino were merged with other data because there was insufficient data from the single 1978 site to extrapolate small differences in succession from species composition which may be more related to site than temporal changes associated with age class. Nineteen perennial and 10 herb species were recorded.

UNBURNED VEGETATION

Unburned perennial cover averaged 21% and was dominated by *Larrea tridentata*, *Ambrosia dumosa*, and *Encelia farinosa* (Table 2). Wash species (*Acacia greggii*, *Beloperone californica*, *Hyptis emoryi*) and cacti (*Opuntia acanthocarpa*, *O. bigelovii*) were occasional in all sites. Native herb cover (*Aristida adscensionis*, *Chaenactis fremontii* and *Chorizanthe brevicornu*) varied greatly while the European exotics, *Bromus rubens* and *Schismus barbatus*, were nearly everywhere (Fig. 2).

BURNED VEGETATION

Fire damage to perennials.—Most perennials were scorched, although the majority of shrubs were locally burned in several sites, particularly the Blaisdell fan. The pattern of shrub damage was species-specific, suggesting that the combustion of shrubs was more influenced by individual species morphology and fuel properties than spatial variations in fire behavior (Table 3). *Larrea tridentata* was typically only scorched despite its resinous foliage and the dense herbaceous cover growing in organically rich eolian sedimentary mounds beneath. Most main stems were unburned and often contained green foliage. Flame heights from herbaceous fuels were apparently insufficient to burn *L. tridentata* canopies owing to limited herbaceous fuels, limited foliar dead fuel content, and spreading branch habit (low fuel continuity). *Encelia farinosa* was mostly scorched due to the morphology of pencil-thick branches which support an umbrella of leaves with few stems beneath. Only leaves and branches near the ground burned, leaving foliage on ultimate stems. *Ambrosia dumosa* regularly burned because the canopy comprises numerous small branches with a finely divided branching pattern close to herbaceous fuels which maximizes fuel continuity, surface to volume ratio and rapid pyrolysis.

The cacti, including *Opuntia acanthocarpa*, *O. bigelovii*, and *Ferocactus acanthodes*, were normally scorched. The dense spines of *O. bigelovii* tended to carry flames up the crown. *Beloperone californica* and *Hyptis emoryi* were usually less damaged than other shrubs, perhaps owing to higher fuel moisture content in wash habitats. *Hyptis emoryi* is characterized by an upward branching habit, and its upper stems extended above flames. Among infrequent shrubs (data not shown), *Acacia greggii* and *Dalea californica* rarely burned because of their arboreal and semideciduous growth habits. *Bebbia juncea*, *Ephedra californica* and *Krameria grayi* normally burned due to their low growth habits and compact crowns.

Sprouting and mortality. Sprouting of most perennials was limited and depended upon local fire intensity. At the heavily burned Blaisdell site, for example, most plants were reduced to ash and mortality was nearly universal; sprouting was intermittent among scorched shrubs at the other sites (Table 3).

Burned shrubs of most species sprouted less than scorched ones. *Larrea tridentata*, *Ambrosia dumosa* and *Encelia farinosa* rarely sprouted even among scorched individuals that retained full canopy foliage. Many *L. tridentata* shrubs with living foliage after burning died later, presumably as a result of basal cambium damage. Scattered resprouts of *Opuntia acanthocarpa*, *O. bigelovii*, *Echinocereus engelmannii* and *Ferocactus acanthodes*

TABLE 2.—Density (D) and cover (C) of established (unburned) and resprouting (burned) shrubs. Density is expressed in number of plants per 100 m², cover in percent ground covered

	Blaisdell				Chino				Palm Canyon				Palm Indian			
	Unburned		Burned		Unburned		Burned		Unburned		Burned		Unburned		Burned	
Species	D	C	D	C	D	C	D	C	D	C	D	C		C	D	C
Larrea tridentata	2.5	3.1	0	0	3.5	3.4	0	0	3.0	4.2	0	0	8.0	13.4	0	0
Ambrosia dumosa	20.0	13.0	0	0	8.0	4.1	0	0	6.0	4.1	1.5	3.3	5.5	1.7	.5	.2
Encelia farinosa	1.0	.9	0	0	11.5	9.2	1.5	2.0	13.0	10.6	2.0	2.6	3.0	1.4	2.5	3.5
Opuntia acanthocarpa	3.0	1.2	0	0					3.0	1.7	1.0	.3	1.0	.2	0	0
O. bigelovii													7.5	1.2	2.0	.5
Hyptis emoryi					0	0	1.0	.8	2.5	3.0	1.0	.7	1.5	1.6	1.0	.6
Krameria grayi	2.5	1.5	0	0	.5	.3	0	0								
Dalea californica	1.0	.4	0	0												
Mirabilis bigelovii	.5	.3	0	0												
Beloperone californica					3.5	2.0	7.0	3.7								
Hilaria rigida					1.0	.5	0	0								
Ferocactus acanthodes					.5	.1	0	0								
Acacia greggii									0	0	.5	1.4				
Bebbia juncea													.5	.9	.5	.6
Echinocereus engelmannii													.5	.1	0	0
Total	30.5	20.4	0	0	28.5	19.6	9.5	6.5	27.5	23.6	6.0	8.3	27.5	20.5	6.5	5.4

were surrounded by numerous skeletons of dead individuals. The wash species *Beloperone californica* and *Hyptis emoryi* exhibited well-developed stump and crown sprouting. *Acacia greggii* resprouted to former canopy cover within 3 years.

SEEDLING ESTABLISHMENT

More shrub seedlings established on burned than on unburned sites, although the pattern of regeneration varied with species and annual precipitation (Table 4). *Encelia farinosa* accounted for most of the seedlings observed during the first growing season, especially in burns. Most reproduction during the first growing season was composed of *Encelia farinosa*, primarily in burns. *Hilaria rigida*, *Opuntia acanthocarpa* and *Trixis californica* seedlings were observed in burns only after the first growing season (1980-1981). *Mirabilis bigelovii*, *Sphaeralcea emoryi* and *Bebbia juncea* also reproduced in burns mostly during the first growing season, but establishment persisted into later growing seasons. *Ambrosia dumosa* and *Ditaxis lanceolata* establishment increased in later growing seasons. Most

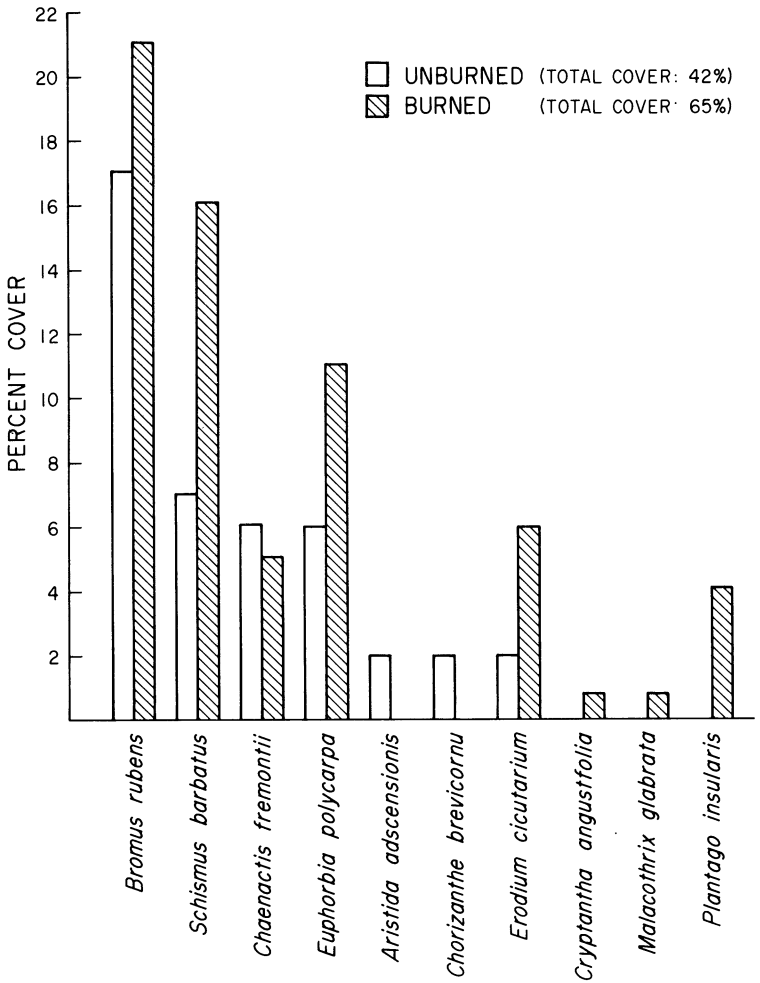


Fig. 2.—Herbaceous cover in burned and unburned sites

seedling reproduction in unburned sites was *E. farinosa* and *A. dumosa*. There was sporadic establishment of *Larrea tridentata* and *Hyptis emoryi*, mostly in unburned sites. The wet 1982-1983 season was followed by abundant reproduction of *E. farinosa* and lesser amounts of *A. dumosa* in both burned and unburned sites.

With the exception of *Encelia farinosa*, seedling densities were less than the density of established shrubs in unburned areas. Severely burned areas with few surviving perennials, such as the Blaisdell fan, had fewest seedlings (Table 2). Several infrequent perennials established no seedlings in the area, including *Acacia greggii*, *Dalea californica*, *Echinocereus engelmannii*, *Ephedra californica*, *Ferocactus acanthodes*, *Frameria grayi* and *Opuntia bigelovii* (removal of adults limited vegetative reproduction in the latter).

CHANGES IN STAND COMPOSITION

The primary effect of recent burns was the reduction of perennial cover, owing to limited sprouting combined with scarce seedling establishment of most shrubs (Fig. 3). After 3-5 growing seasons, the total cover in burned sites was about half that of unburned sites and was composed mostly of *Encelia farinosa*. The largest change was the reduction of *Larrea tridentata* because it experienced almost no sexual or asexual reproduction or resprouting.

TABLE 3.—Shrub damage, sprouting and mortality (percent)

Species	N	Burned	Resprouts	Scorched	Resprouts	Green	Resprouts	Mortality
Encelia farinosa	122	20	0	78	5	2	2	93
Ambrosia dumosa	84	81	2	16	6	3	3	89
Opuntia bigelovii	49	4	0	94	6	2	2	92
O. acanthocarpa	36	11	0	89	8	0	0	92
Larrea tridentata	35	0	0	100	3	0	0	97
Hyptis emoryi	10	0	0	100	40	0	0	60
Beloperone californica	7	0	0	100	57	0	0	43

TABLE 4.—Seedling density in initial and subsequent growing seasons

	Burned Area		Unburned Area	
Species	1980-1981* growing season (number/ha)	1981-1983* growing seasons (number/ha)	1980-1981* growing season (number/ha)	1981-1983* growing seasons (number/ha)
Encelia farinosa	1460	7010	90	5650
Hyptis Emoryi	90	50	10	30
Mirabilis bigelovii	90	40	0	0
Hilaria rigida	80	0	0	0
Ambrosia dumosa	*60*	*160*	*30*	*200*
Sphaeralcea emoryi	50	10	0	0
Bebbia juncea	50	30	0	0
Beloperone californica	40	40	0	0
Opuntia acanthocarpa	30	0	0	0
Ditaxis lanceolata	10	60	0	0
Trixis californica	10	0	0	0
Larrea tridentata	0	10	0	40

*At the Chino site, the first growing season was 1978-1979. Later growing seasons are 1979-1983

Postfire herb cover averaged 23% greater in burned than unburned stands. *Malacothrix glabrata*, *Cryptantha angustifolia* and *Plantago insularis* were found only in burned areas. Most cover was of exotic European annuals *Bromus rubens* and *Schismus barbatus* (Fig. 2).

DISCUSSION

Fire mortality and postfire succession in creosote bush scrub at Palm Springs are similar to other studies in the Sonoran Desert (Rogers and Steele, 1980; O'Leary and Minnich, 1981). Sprouting behavior of *Larrea tridentata* in the Sonoran Desert was varia-

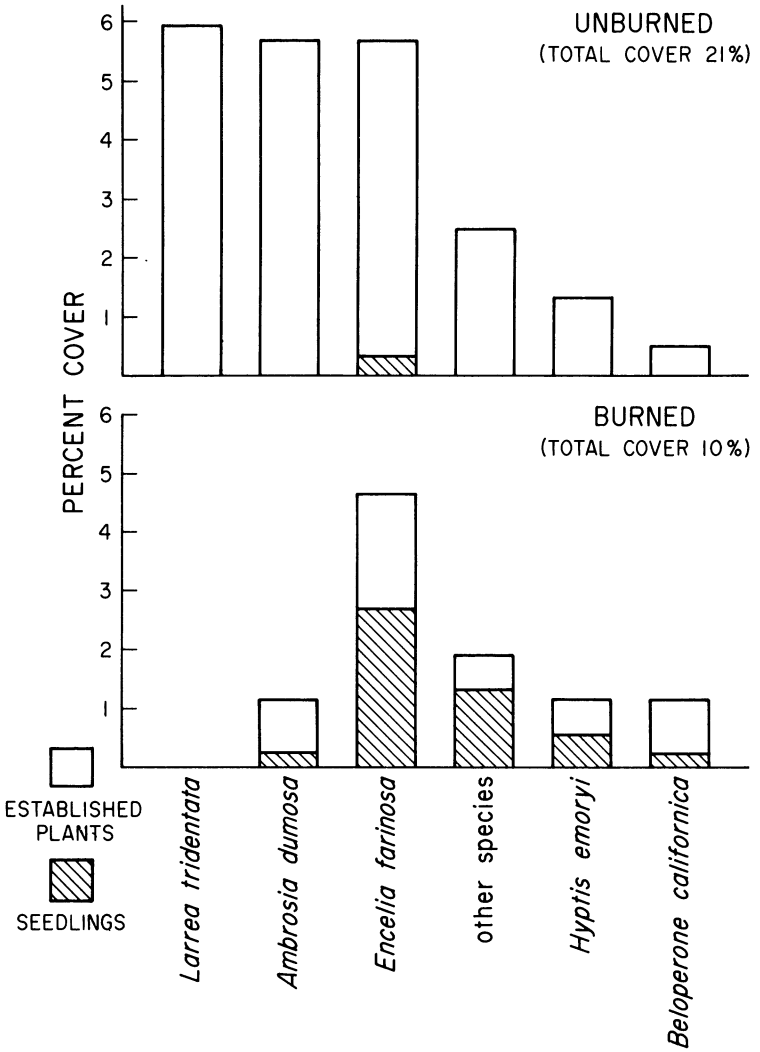


Fig. 3.—Perennial cover in burned and unburned sites (cover expressed in absolute percentages). "Other species" include *Acacia greggii*, *Bebbia juncea*, *Dalea californica*, *Echinocereous engelmannii*, *Ephedra californica*, *Ferocactus acanthodes*, *Hilaria rigida*, *Krameria grayi*, *Opuntia acanthocarpa* and *O. bigelovii*, *Ditaxis lanceolata*, *Mirabilis bigelovii*, *Spheralcea emoryi* and *trixis californica*

ble, depending primarily on fire intensity and season. Dalton (1962) found that slightly to moderately burned *L. tridentata* near Tucson, Arizona, experienced 60-70% mortality. Rogers and Steele (1980) observed minimal resprouting of *L. tridentata*. However, fire intensity and season were not reported. White (1968) found that *L. tridentata* mortality was related to season of burning, with highest mortality prior to the onset of the summer precipitation season. Increased fire intensity and duration also resulted in decreased sprout production.

At Palm Springs, sprouting of *Larrea tridentata* was highly variable in burns which occurred from June through September. O'Leary and Minnich (1981) found moderate sprouting following the July 1973 burn. We observed nearly 100% sprouting following a small burn near Snow Creek in June 1983, but heavy mortality in another burn 2 weeks later 10 km NW. The 1980 burns (July, August-September) caused heavy mortality. These trends indicate that sprouting rates are more related to fire intensity than season of burning.

Heavy *Encelia farinosa* and *Ambrosia dumosa* mortality at Palm Springs parallels findings in Arizona (*A. deltoides*: Rogers and Steele, 1980) and California coastal sage scrub (Malanson and O'Leary, 1982). The reduction of *Opuntia acanthocarpa*, and *O. bigelovii* is comparable to that in burns at Snow Creek (O'Leary and Minnich, 1981), the Borrego Desert (Tratz and Vogl, 1977), and Arizona (Rogers and Steele, 1980). The vigorous sprouting of wash species (*Hyptis emoryi*, *Beloperone californica*, and *Acacia greggii*) at Palm Springs was also observed in similar habitats in the Borrego Desert (*Chilopsis linearis*, *A. greggii*, Tratz and Vogl, 1977). Such sprouting behavior may be a generalized adaptation to flash flood disturbances (Tratz, 1978; Zedler, 1981).

Poor seedling establishment at Palm Springs is probably unrelated to seed availability since all species occur in adjacent unburned areas. Most are capable of long-range seed dispersal by wind (*Larrea tridentata*, *Ambrosia dumosa* and *Encelia farinosa*) or fauna (*Opuntia bigelovii* [vegetative reproduction], *O. acanthocarpa*, *Hyptis emoryi* and *Beloperone californica*) (Ridley, 1930). Scattered resprouts and unburned individuals throughout the burns provide local seed sources. Thus, postfire habitats were apparently unfavorable for establishment.

Reproduction may be encouraged by disturbance. In powerline and road construction disturbances in the Mojave Desert, seedling establishment was most prolific among short-lived species, primarily *Encelia frutescens*, while germination of most long-lived species, including *Larrea tridentata* was limited (Vasek, 1980). We found no evidence of abundant *L. tridentata* reproduction, as reported in Arizona burn sites (Dalton, 1962). In an investigation following severe flooding near Ocotillo, Calif., Zedler (1981) recorded abundant reproduction of *Ambrosia dumosa*, *E. farinosa*, *Larrea tridentata*, *Opuntia echinocarpa*, *Acacia greggii*, *Hyptis emoryi* and *Beloperone californica*. Since postfire establishment was limited in the Palm Springs sites, prolonged surface moisture from abundant rainfall or floodwaters may be required for comparable germination and establishment.

Season of rainfall may have inhibited establishment of several shrubs. In Joshua Tree National Monument (50 km NE), Went (1948) found that *Acacia greggii*, *Dalea* spp., *Hymenoclea salsola*, *Hyptis emoryi* and *Larrea tridentata* germinated only in summer. Beatley (1974) suggested that summer rainfall is a requirement for successful germination of *L. tridentata*. However, unusually heavy summer rains at Palm Springs in August 1979 (44 mm), and the two wettest summers of the century (1983, 1984) resulted in only sporadic establishment of these shrubs. Similarly, Vasek (1980) found only limited germination of long-lived shrubs and succulents, including *L. tridentata*, *Opuntia acanthocarpa*, *Krameria grayi*, *Hilaria rigida*, in the Mojave Desert, despite favorable climatic conditions. *Encelia farinosa* responded prolifically to heavy winter rains of 1982-1983, a trend consistent with its distribution in coastal sage scrub of coastal southern California where summer rain is nearly absent. Zedler (1981) also observed heavy summer germination of this scrub.

Vasek (1980) suggested that soil condition, primarily the accumulation of organic

matter, is important for germination. Many perennials at Palm Springs established seedlings only in burns. *Encelia farinosa* and *Ambrosia dumosa* establishment was also initially stimulated in burns. However, both shrubs colonized both burned and unburned sites after the wet 1982-1983 winter.

Desert succession studies elsewhere in California (Vasek *et al.*, 1975a, b; Vasek, 1980, 1983) indicate that most long-lived shrubs (*Larrea tridentata*, *Ambrosia dumosa*, *Opuntia bigelovii*, *Echinocereus engelmannii*, *Acacia greggii* and *Krameria parvifolia*) are characterized by limited but continuous establishment and thus respond negatively to disturbance. The chronic disturbance of desert habitats by wind and water erosion permits suitable sites for both short- and long-lived perennials. Creosote bush scrub stands are reported to occur in various successional states indicating continuous establishment. Postdisturbance regeneration may take hundreds of years to complete, being very slow at first (Vasek, 1980). The scale of such disturbances, however, is much smaller than wildland fires which can remove plant cover over extensive areas and exacerbate reestablishment by long-range seed dispersal.

The limited period of succession considered here permits only speculation on the future postfire succession at Palm Springs. Long-lived species were nearly eliminated and replaced by short-lived shrubs, mostly *Encelia farinosa*, with wash species persisting locally through sprouting. To date, there is little evidence of continuous long-lived perennial replacement as reported by Vasek *et al.* (1975b), in spite of favorable conditions provided by abnormally heavy precipitation. Indeed, 1984 aerial photographs (1:24,000; Riverside County Flood Control) indicate that *Larrea tridentata* has been removed from extensive areas of the San Jacinto Mountains. An open *Encelia farinosa* community now covering the slopes may persist for decades.

FIRE, CREOSOTE BUSH SCRUB STABILITY AND BIOGEOGRAPHY

In contrast with fire-prone chaparral and forest ecosystems covering the mountains of coastal California, many desert perennials appear unable to persist after burns by surviving fires, sprouting, fruit serotiny, long-term seed viability and immediate germination by scarification of soil seed (*see* reviews by Hanes, 1977; Wright, 1982; Reid and Oechel, 1984). Indeed, the rapid transformation of perennial cover and floristic composition of stands in the Palm Springs burns suggests that many creosote bush scrub taxa are poorly adapted to recurrent burning. Recurrent fire appears to select for short-lived desert shrubs, notably *Encelia farinosa* and *Ambrosia dumosa*, at the expense of long-lived species. At the Blaisdell site, the 1983 burn was carried entirely by herbs and eliminated the few shrubs which survived the 1980 burn. Field observations indicate that *Larrea tridentata* and *Opuntia echinocarpa* surviving a 1973 burn at Snow Creek were removed by the 1982 burn; the site is now covered by *Hymonoclea salsola* and annual grasses (*cf.*, O'Leary and Minnich, 1981).

The recent outbreak of fires, however, is clearly related to persistent above-normal precipitation and increases in native and exotic herb cover after 1976. It is important to ask whether recent burns are an aberration, and thus represent only an ephemeral event in creosote bush scrub ecology and biogeography.

Low mean annual precipitation and plant productivity at Palm Springs normally precludes short-term fire recurrences. Indeed, chaparral fires crossing the desert flanks of the San Jacinto Mountains earlier in the century stopped above desert scrub communities, owing apparently to limited fuel. Prehistoric burns doubtless extended into the desert margin on occasion when conditions were optimal. Disturbance intervals, however, were sufficiently long, perhaps centuries, to permit the establishment of long-lived desert perennials.

The western geographic limits of many taxa may thus be related to repeated, more intense burning associated with coastal sage scrub and chaparral. In southern California coastal sage scrub, burns are followed by rapid seedling establishment of *Eriogonum fasciculatum*, *Encelia farinosa*, *Salvia apiana*, *Salvia mellifera* and *Artemesia californica*, although

resprouting is occasional (Malanson and O'Leary, 1982). Creosote bush scrub and coastal sage scrub are similar in that both ecosystems comprise mostly drought-deciduous mesophytic subshrubs. However, creosote bush scrub perennials, with the exception of *Salvia apiana* and *Encelia farinosa*, are poor colonizers following recurrent fire (Tratz, 1978). Indeed, recent burns have converted creosote bush scrub at Palm Springs to *Encelia farinosa* coastal sage scrub similar to stands covering semiarid interior valleys around Riverside, California.

Some desert taxa, including *Yucca schidigera*, *Simmondsia chinensis*, *Acacia greggii*, *Juniperus californica* and *Opuntia occidentalis*, extend westward into fire-prone areas of coastal southern California. These shrubs, however, are either vigorous sprouters (Tratz, 1978) or restricted to drier sites within the Pacific slope, such as at Aguanga and the Perris Plain in rain shadows of coastal ranges, and porous alluvial fans descending from the San Gabriel and San Bernardino mountains, where burning intervals are locally lengthened by low productivity (Axelrod, 1966; Smith, 1980).

The role of European exotics.—Recent burns, however, may have been encouraged by the profusion of European exotic grasses, especially *Bromus tectorum*, *B. rubens* and *Schismus barbatus*, during recent wet years. These species have continued to thrive during drier years since 1983. At Palm Springs, *B. rubens*, *Schismus barbatus* and other European grasses escape excessive summer heat through their winter annual habit. A minimum of cool-season precipitation (ca. 150 mm) appears sufficient to support these exotic grasses. In the dry interior, herbaceous cover resists decomposition resulting in accumulation of flammable fuels. Moreover, since exotic taxa may use desert habitats in ways distinct from indigenous taxa, consequent increases in herbaceous cover may thus increase fire frequencies and change the biogeography of creosote bush scrub without changes in climate.

LITERATURE CITED

AXELROD, D. I. 1966. The Pleistocene Soboba flora of southern California. *Univ. Calif. Publ. Geol. Sci.*, **60**:1-79.

BAILEY, H. P. 1966. Climate of southern California. Univ. of Calif. Press, Berkeley. 87 p.

BEATLEY, J. C. 1974. Effects of rainfall and temperature on the distribution and behavior of *Larrea tridentata* (Creosotebush) in the Mojave Desert of Nevada. *Ecology*, **55**:245-261.

BURK, J. H. 1977. Sonoran Desert, p. 869-889. *In*: M.G. Barbour and J. Major (eds.). Terrestrial vegetation of California. John Wiley and Sons, New York.

CALIFORNIA DEPARTMENT OF WATER RESOURCES. 1984. California rainfall summary. Monthly total precipitation. 1849-1984.

CANFIELD, R. H. 1942. Application of the line intercept method in sampling range vegetation. *J. For.*, **39**:338-394.

DALTON, P. D. 1962. Ecology of the creosotebush *Larrea tridentata* (D.C.) Cov., Ph.D. Dissertation, University of Arizona, Tucson. 162 p.

FRASER, D. M. 1931. Geology of the San Jacinto quadrangle south of San Gorgonio Pass, California. *Calif. Div. Mines Geol. Mining Calif.* **27**:494-540.

HANES, T. L. 1977. Chaparral, p. 417-469. *In*: M.G. Barbour and J. Major (eds.). Terrestrial vegetation of California. John Wiley and Sons, New York

HUMPHREY, R. R. 1949. Fire as a means of controlling velvet mesquite, burroweed, and cholla on southern Arizona ranges. *J. Range Manage.*, **2**:175-182.

_____. 1962. Range ecology. The Ronald Press Co., New York, 234 p.

JOHNSON, H. B. 1974. Vegetation and plant communities of southern California—a functional view, p. 125-162. *In*: J. Latting (ed.). Plant communities of Southern California. Southern California Native Plant Society, Spec. Publ. no. 2.

KNECHT, A. A. 1980. Soil survey of Riverside County, California: Coachella Valley area. *U.S. Dep. Agri. Soil Conser. Serv. Soil Surv.* 89 p.

MALANSON, G. P. AND J. F. O'LEARY 1982. Post-fire regeneration strategies of Californian coastal sage shrubs. *Oecologia*, **53**:355-358.

MCHARGUE, L. T. 1973. A vegetational analysis of the Coachella Valley, California. Ph.D. Dissertation, University of California, Irvine. 364 p.

MUELLER-DOMBOIS, D. AND H. ELLENBERG. 1974. Aims and methods of vegetation ecology. John Wiley and Sons, New York. 547 p.

O'LEARY, J. F. AND R. A. MINNICH. 1981. Postfire recovery of creosote bush scrub vegetation in the western Colorado Desert. *Madroño*, **28**:61-66.

PROCTOR, R. J. 1968. Geology of the Desert Hot Springs-upper Coachella Valley area, California. *Calif. Div. Mines Geol. Spec. Rep. No. 94.* 50 p.

REID, C. AND W. OECHEL. 1984. Vegetation processes following fire, p. 25-41. *In*: J. J. Devries (ed.). Shrublands in California: Literature review and research needed for management. University of California, Davis. Water Resources Center. Contrib. No. 191.

RIDLEY, H. N. 1930. The dispersal of plants throughout the world. L. Reeve & Co., London. 744 p.

ROGERS, G. F. AND J. STEELE. 1980. Sonoran Desert fire ecology p. 15-19. *In*: Proceedings of the fire history workshop. *U.S. For. Serv. Gen Tech. Rep. RM-81.* Fort Collins, Colorado. 142 p.

SHREVE, F. AND I. L. WIGGINS. 1964. Vegetation and flora of the Sonoran Desert. Stanford Univ. Press, Stanford, California. 1740 p.

SMITH, R. L. 1980. Alluvial scrub vegetation of the San Gabriel River flood plain, California. *Madroño*, **27**:126-138.

TRATZ, W. M. 1978. Postfire vegetational recovery, productivity and herbivore utilization of a chaparral-desert ecotone. M.S. Thesis, Cal. State University, Los Angeles. 74 p.

_____ AND R. J. VOGL. 1977. Postfire vegetational recovery, productivity, and herbivore utilization of a chaparral-desert ecotone, p. 426-430. *In*: H. A. Mooney and C. E. Conrad (eds.). Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems. 1-5 August 1977. Palo Alto, Calif. *U.S. For. Serv. Gen. Tech. Rep. WO-3.*

VASEK, F. C., 1980. Early successional stages in Mojave Desert scrub vegetation. *Isr. J. Bot.*, **28**:133-148.

_____. 1983. Plant succession in the Mojave Desert. *Crossosoma*, **9**:1-23.

_____, H. B. JOHNSON AND G. D. BRUM. 1975a. Effects of power transmission lines on vegetation of the Mojave Desert. *Madroño,* **23**:114-130.

_____, _____ AND D. H. ESLINGER. 1975b. Effects of pipeline construction on creosote bush scrub vegetation of the Mojave Desert. *Ibid.*, **23**:1-13.

WENT, F. W. 1948. Ecology of desert plants: I. Observations on germination in the Joshua Tree National Monument, California. *Ecology,* **29**:242-253.

WHITE, L. D. 1968. Factors affecting susceptibility of creosotebush (*Larrea tridentata*) (*D.C.*) *Cov.* to burning. Ph.D. Dissertation, University of Arizona, Tucson. 96 p.

WRIGHT, H. E. 1982. Fire ecology, United States and Canada. Wiley, New York. 501 p.

ZEDLER, P. H. 1981. Vegetation change in chaparral and desert communities in San Diego County, California, p. 406-424. *In*: D. C. West, H. H. Shugart and D. B. Botkin (eds.). Forest succession: Concepts and application. Springer-Verlag, New York, N.Y.

SUBMITTED 1 JULY 1985 ACCEPTED 18 FEBRUARY 1986

Anthropogenic Degradation of the Southern California Desert Ecosystem and Prospects for Natural Recovery and Restoration

JEFFREY E. LOVICH
US Geological Survey
Western Ecological Research Center
Department of Biology, University of California
Riverside, California 92521-0427 USA

DAVID BAINBRIDGE
United States International University
Environmental Studies Program
10455 Pomerado Road
San Diego, California 92131-1799 USA

ABSTRACT / Large areas of the southern California desert ecosystem have been negatively affected by off-highway vehicle use, overgrazing by domestic livestock, agriculture, urbanization, construction of roads and utility corridors, air pollution, military training exercises, and other activities. Secondary contributions to degradation include the proliferation of exotic plant species and a higher frequency of anthropogenic fire. Effects of these impacts include alteration or destruction of macro- and micro-vegetation elements, establishment of annual plant communities dominated by exotic species, destruction of soil stabilizers, soil compaction, and increased erosion. Published estimates of recovery time are based on return to predisturbance levels of biomass, cover, density, community structure, or soil characteristics. Natural recovery rates depend on the nature and severity of the impact but are generally very slow. Recovery to predisturbance plant cover and biomass may take 50–300 years, while complete ecosystem recovery may require over 3000 years. Restorative intervention can be used to enhance the success and rate of recovery, but the costs are high and the probability for long-term success is low to moderate. Given the sensitivity of desert habitats to disturbance and the slow rate of natural recovery, the best management option is to limit the extent and intensity of impacts as much as possible.

We've mined it, dammed it, irrigated it, developed it, and subjected it to nuclear assault, yet the desert, somehow both fragile and tough, manages to endure, a rugged old touchstone for us to measure ourselves against.

Malcolm Jones, Jr., 1996

The landscape and native vegetation of the southern California deserts have been significantly altered during the last century by a variety of factors including: livestock grazing (Bentley 1898, Humphrey 1958), introduction of exotic species (Mooney and others 1986, Rejmánek and Randall 1994), off-road vehicle use (see reviews in Webb and Wilshire 1983), urbanization and its attendant effects (Reible and others 1982, Walsh and Hoffer 1991), and military activities (Lathrop 1983a, Prose and others 1987). Extreme temperatures, intense sun, high winds, limited moisture and the low fertility of desert soils make natural recovery of the desert very slow after disturbance (Bainbridge and Virginia 1990). Conditions suitable for plant establishment occur only infrequently and irregularly, and it may take hundreds of years for full recovery to take place without active intervention. Many of the actions of desert development and utilization have profound effects on ecosystem stability, diversity, and productivity (Rundel and Gibson 1996).

KEY WORDS: Mojave Desert; Colorado Desert; California; Human impacts; Recovery; Restoration

The literature on human impacts to the biotic and physical components of the Mojave Desert is large and diffuse. In this paper we review the major human-induced impacts on the California desert, and the prospects for natural recovery and restoration, by characterizing the effects of past actions on the Mojave Desert ecosystem and other arid lands. In addition, we briefly suggest practical strategies and methods for planning and implementing desert restoration projects and improving recovery of these areas by soil management, transplanting, direct seeding, and other techniques.

Area of Study

Our review focuses on the Mojave and Colorado Deserts of southern California, an area of approximately 10 million ha. The Mojave Desert occupies portions of Inyo, Kern, Los Angeles, Riverside, and San Bernardino counties in California. The geographical and ecological boundaries of the Mojave Desert are

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discussed in detail by Vasek and Barbour (1977) and Hickman (1993). The modern plant community of the Mojave has been characterized as ''desert scrub'' (Turner 1982, Hickman 1993), even though it is composed of several recognizable community types including: creosote bush scrub, saltbush scrub, shadscale scrub, blackbush scrub, and Joshua tree woodland (Vasek and Barbour 1977). Perennial plant diversity is low compared to the Colorado Desert: areas dominated by *Larrea tridentata* and *Ambrosia dumosa* occupy about 70% of the Mojave (Lathrop and Rowlands 1983). More than 250 species of annual plants are found in the Mojave, including 80–90 species that are endemic (Turner 1982). In Death Valley and the Salton Sink, annuals account for 42% and 47% of the local flora, respectively (Johnson and others 1978). Overall plant diversity is low below 1000 m, but increases to levels approaching more temperate habitats at higher elevations (Cody 1986).

The Colorado Desert is that part of the Sonoran Desert found mostly in Imperial and Riverside counties, California (Burk 1977). The Colorado Desert is generally separated from the Mojave Desert to the north by the Little San Bernardino, Cottonwood, and Eagle Mountains. The boundary between the two desert ecosystems is poorly defined to the east of these mountain ranges (Vasek and Barbour 1977). A bimodal rainfall pattern composed of winter frontal systems and summer convectional storms distinguishes the Colorado Desert from the western Mojave Desert (Burk 1977), where most precipitation comes from winter rains. In addition, the region is generally lower, flatter, hotter in the summer and warmer in the winter, and hosts a slightly different flora than the Mojave Desert (Hickman 1993). Dominant vegetation in the Colorado Desert is ''Sonoran creosote–bush scrub'' (Hickman 1993). Plant communities recognized by Burk (1977) include creosote bush scrub, cactus scrub, wash woodland, palm oasis, saltbush scrub, and alkali scrub. There is broad overlap of plant species between the Mojave and Colorado Deserts, but there are a significant number of freeze-sensitive arboreal species that are found only in the Colorado Desert.

Both deserts are characterized by dominant perennial plant species that are long-lived (Bowers and others 1995), some exceptionally so (Vasek 1980). Density and cover of long-lived species increases with age of the site surface (Webb and others 1987, 1988, Bowers and others 1997).

While our focus is specifically directed to the problems of desert lands in California (most of our experience is in the Colorado Desert), we believe our review will prove useful for desert management in other parts of the Southwest, northern Mexico, and in other drylands around the world.

Factors Contributing to Habitat Degradation

The following sections summarize major anthropogenic degradation factors in the southern California desert ecosystem other than agricultural development and urbanization. An understanding of the nature and the effect of disturbances is useful in estimating recovery times or determining what course of action may be required to restore a habitat. Table 1 summarizes the estimated time intervals required for affected plant communities to fully or partially recover from human-induced disturbances.

Impacts on the desert can be loosely divided into historic and current impacts. There is rarely a complete distinction between the two but, in general, the historic impacts include such things as overgrazing, aqueduct building, and the operation of the Desert Training Center in World War II. Grazing still continues, but the major impacts from grazing occurred in the mid to late 1800s. A very rough estimate of the magnitude and extent of these different activities is shown in Table 2. The following factors are not presented in order of importance.

Livestock and Grazing

Cattle and sheep have grazed almost continuously through large areas of the region from the mid-1800s to the present, although the numbers have dropped off in recent years. The establishment of ranching fostered the development of a major industry in the western United States that prospered until droughts, harsh winters, and overgrazing caused a series of dramatic herd declines in the late 1800s. Populations of sheep (60,000) and cattle (67,000) peaked in Imperial County in 1920. In 1968 there were 25,000 cattle and 138,000 sheep grazing on Bureau of Land Management (BLM) and National Monument desert lands in California, predominantly in the Mojave (Ruch 1968). In 1979, 1.8 million ha of public lands administered by the BLM in the California desert were grazed by 75,000 sheep and 14,000 cattle (Bureau of Land Management 1980). Excellent histories of grazing in the desert southwest are provided by Humphrey (1958, 1987).

No published studies have yet fully documented the impact of grazing by livestock in the California desert or estimated the time required for heavily grazed areas to recover to pregrazing levels of plant diversity, density, and cover (Oldemeyer 1994). The rarity of undisturbed reference sites and long-term studies makes it difficult to quantify the effects of grazing, but it is possible to

Table 1. Estimated natural recovery times in years for California desert plant communities subjected to various anthropogenic impacts

Impact	Location	$T_{recovery}$	Reference
Tank tracks (military)	eastern Mojave	65,[a] 76[b]	Lathrop (1983a)
Tent areas (military)	eastern Mojave	45,[a] 58[b]	Lathrop (1983a)
Dirt roadways (military)	eastern Mojave	112,[a] 212[b]	Lathrop (1983a)
Tent sites (military)	eastern Mojave	8–112[c]	Prose and Metzger (1985)
Tent roads (military)	eastern Mojave	57–440[c]	Prose and Metzger (1985)
Parking lots (military)	eastern Mojave	35–440[c]	Prose and Metzger (1985)
Main roads (military)	eastern Mojave	100–infinity[c]	Prose and Metzger (1985)
Military	eastern Mojave	1500–3000[d]	Prose and Metzger (1985)
Townsites	northern Mojave	80–110,[e] 20–50,[b] 1000+[f]	Webb and Newman (1982)
Pipeline	southern Mojave	centuries[g]	Vasek et al. (1975a)
Powerline	southern Mojave	33[h]	Vasek et al. (1975b)
Fire	western Colorado Desert	5[b,i]	O'Leary and Minnich (1981)
Off-road vehicle use	western Mojave	probably centuries	Webb et al. (1983)
Pipeline (berm and trench)	Mojave Desert	100[j]	Lathrop and Archbold (1980b)
Pipeline (road edge)	Mojave Desert	98[j]	Lathrop and Archbold (1980b)
Powerline pylons and road edges	Mojave Desert	100[j]	Lathrop and Archbold (1980b)
Under powerline wires	Mojave Desert	20[j]	Lathrop and Archbold (1980b)

[a]Recovery time to control density.

[b]Recovery time to control cover.

[c]Estimated recovery time for *Larrea tridentata* to reach control densities.

[d]Estimated recovery time (''if at all'') for recovery to original vegetative structure assuming establishment of control densities.

[e]Compaction recovery time.

[f]Total estimated recovery time.

[g]30–40 years assuming linear rates of succession; 3000 years until formation of large creosote clonal rings.

[h]Incomplete recovery time in areas of high impact.

[i]Time for appearance of perennial seedlings. See Brown and Minnich (1986) in section on fire.

[j]Biomass recovery assuming that successional vegetative growth is approximated by a straight line. Recovery of long-lived species is estimated to take at least three times longer than indicated.

Table 2. Adverse impacts on California desert, their relative intensity and historical occurrence

Impact	Intensity	Current/historic
Grazing	moderate	primarily historic
Removal of native people	moderate	historic
Invasive plants	moderate/severe	historic/current
Highways	severe	current
Urbanization	severe	current
Off-road vehicles	severe	current
Agriculture	severe	both
Military operations	severe	both
Mining	locally severe	both
Linear corridors	locally severe	current

describe the nature of these impacts and their probable extent. Consequently, conclusions about the effects of grazing on arid ecosystems have been contradictory and controversial (Anonymous 1991, Borman and Johnson 1990, Coe 1990, Field 1990, General Accounting Office 1992, Gillis 1991, Poling 1991). Some argue that grazing is beneficial to rangelands, suggesting that the act of grazing stimulates new plant growth (Savory 1988). Other putative positive benefits include the dispersal of seeds, production of fertilizer in the form of excrement, and churning of soil generated by moving hooves (but see Balph and Malecheck 1985). Others point to negative impacts of grazing including: soil compaction and increased erosion, trampling of plants, and overcropping. Grazing effects on arid ecosystems are reviewed in detail by Archer and Smeins (1991).

The effects of overgrazing are far less controversial. As early as the late 1800s there was recognition of dramatic range deterioration in the United States as a result of overstocking of cattle (Bentley 1898). In his report, Bentley concluded that ''The ranges have been almost ruined, and if not renewed will soon be past all hope of permanent improvement.'' In spite of early recognition of a problem, solutions have still not been satisfactorily implemented (General Accounting Office 1992).

The impacts of grazing, whether positive or negative, may be extensive. In a recent biological assessment in the western Mojave Desert of California, 100% of a 234-square-km area was impacted to some extent by

sheep grazing (Tierra Madre Consultants 1991). In a detailed analysis of the effects of sheep grazing on 2.6 square km of desert tortoise habitat, Nicholson and Humphreys (1981) observed soil disturbances in 80% of the area used by sheep. Thirty-three percent of the plot was heavily used by sheep.

Livestock grazing, by its very nature, causes a decrease in plant cover and biomass, at least initially. Decreases in cover have been shown to be associated with a decrease in the diversity and abundance of lizards and other wildlife species in arid ecosystems (Busack and Bury 1974, Germano and Hungerford 1981, Germano and others 1983, Germano and Lawhead 1986). In the Mojave Desert Nicholson and Humphreys (1981) observed large decreases in plant cover in areas grazed by sheep. Similar results were reported by Webb and Stielstra (1979) in the Mojave. In addition, they observed a 60% reduction in above-ground biomass on plots grazed by sheep. Other studies, in American deserts outside of the Mojave Desert, have not detected appreciable differences between grazed and ungrazed plots (Heske and Campbell 1991, Rice and Westoby 1978), but most sites had been grazed before the studies were initiated. An important point to make is that the response of plants to grazing varies according to species, season, plant phenology (Genin and Badan-Dangon 1991), local conditions (drought, edaphic factors, etc.), and past historical use.

Direct effects of grazing on desert animals such as the desert tortoise (*Gopherus agassizii*) are not well documented. Grazing sheep can damage tortoise burrows. Nicholson and Humphreys (1981) reported that of 164 tortoise burrows on a 2.6-square-km study site, 10% were damaged and 4% were destroyed. Most burrows were well protected since they were generally located under shrub cover. Damage was considered to be insignificant since tortoises were often observed digging new burrows in late spring regardless of the availability of existing burrows. Others have gone so far as to suggest that cattle dung actually serves as an important food supply for desert tortoises (Bostick 1990), although this has never been rigorously substantiated (Hal Avery personal communication).

Webb and Stielstra (1979) observed that soils in the Mojave Desert exhibited greater surface strength in areas where sheep bedded and grazed relative to control areas. The greatest compaction occurred in the upper 10 cm but compaction was also observed at lower depths. At the surface, soils are trampled by grazing, often obliterating cryptobiotic soil crusts leading to increased erosional potential. Erosion is of special concern for desert soils because the nutrient capital is often concentrated in the surface soil. Gross disorganization of community structure is possible with the loss of only a few centimeters of soil (Charley and Cowling 1968).

Even limited grazing can cause significant shifts in vegetation and damage to soil crusts. Kleiner and Harper (1977) found that seven plant species that were common in the ungrazed area were absent or insignificant in a comparable grazed section of Canyonlands National Park. They attributed this in part to changes in cryptobiotic soil crust, which decreased from 38% cover in the ungrazed area to 5% in the lightly grazed area. Grazing also increases the spatial and temporal heterogeneity of water, nitrogen, and other soil resources, fostering increased desertification of productive arid lands (Schlesinger and others 1990).

As stated above, the rate of natural recovery of habitats exposed to grazing depends on the intensity of past grazing and local conditions. In a blackbrush (*Coleogyne ramosissima*) association in Utah and Arizona, shrub cover is greater in areas that have never been grazed than in grazed areas. In the same area, plots protected from grazing for ten years showed no difference from heavily grazed areas indicating slow rates of recovery (Jeffries and Klopatek 1987). Exclusion of grazing for 14–19 years did not allow recovery of native perennial grasses in southeastern Arizona (Roundy and Jordan 1988). In the deserts of Kuwait land degradation does not necessarily stop following protection from grazing (Omar 1991). Drought, erosion, and sand encroachment continue to degrade land in the absence of grazing. Human activities and grazing may hasten degradation, but in concert with drought the three can be devastating.

In a recent review of the effects of grazing on public land in the hot deserts (Chihuahuan, Mojave, and Sonoran) of the American Southwest, the General Accounting Office (1992) concluded that a high environmental cost has been exacted on these fragile ecosystems and that land degradation due to grazing is continuing. The report concluded by noting that the high environmental risks, budgetary costs, low economic benefits, and management problems associated with livestock grazing on hot desert public lands merits Congressional consideration. Recommended options included raising grazing fees or appropriating additional funds to offset costs of administration and monitoring, and discontinuing livestock grazing altogether in hot desert areas.

Different plant communities respond to grazing in a variety of ways related to a complexity of factors. Results for the Mojave Desert suggest that livestock grazing can have locally significant effects on the plants (Figure 1) and ultimately on desert wildlife. Efforts to restore

Figure 1. Cattle grazing can have locally significant effects on vegetation and soils, as shown in this photo of a cattle watering area and corral in what is now the Mojave National Preserve, California. Note the almost total destruction of perennial plants in the immediate area. The visual effect is greatly diminished as distance from the watering area increases. Photo by Jeff Lovich.

degraded rangeland in the Mojave should start by considering the effects of grazing and the potential impacts of soil compaction, erosion, and plant community alteration.

Linear Corridors

Roads, railways, powerlines, and pipelines, some of the most conspicuous elements of the modern Mojave Desert landscape, are all characterized by long and relatively narrow corridors of disturbance. The fact that most linear corridors are narrow does not necessarily imply that their impacts are minimal. According to Brum and others (1983), over 8000 km of overhead power transmission lines were present in the California desert in 1980, impacting more than 28,000 ha of land. An additional 50,000 ha of land will be impacted by the year 2000 if the projected threefold increase in power demand is accurate. Information summarized in the California Desert Conservation Area Plan (Bureau of Land Management 1980) suggests that an additional 2000 km of energy production and utility corridors are needed to meet the needs of southern California to the year 2000.

The immediate effect of linear corridor construction on soil conditions and plant cover is one of nearly complete destruction (Vasek and others 1975a). In some cases recovery is retarded due to operation and maintenance of corridors (Artz 1989). Other negative secondary effects of corridors include mortality of animals along roadways (Rosen and Lowe 1994, Boarman and Sazaki 1996), habitat fragmentation and restriction of movements and gene flow, increased access to remote areas for illegal collection and vandalism of plants and animals (Nicholson 1978, Garland and Bradley 1984, Boarman and Sazaki 1996, Jennings 1991), and increased erosion (Wilshire and Prose 1987). The steel towers associated with many electrical energy transmission corridors provide nest sites and hunting perches for ravens (*Corvus corax*), a native predator that has increased dramatically in recent years due to human subsidy. The towers may allow ravens to hunt more effectively for the federally threatened desert tortoise (*Gopherus agassizii*) and other desert wildlife (Boarman 1993). Corridors can also serve as a source of exotic invasive plants brought in on construction equipment (Zink and others 1995). Invasive plants prosper in the disturbed conditions and contribute to an increased likelihood of fire. The construction of pipelines for gas, oil, and water and much more destructive than overhead lines because extensive trenching is usually required. This traditionally has led to severe soil impacts (leaving subsoil on the surface), disturbing stabilized crusts and rock surfaces, and concentrating runoff and erosion. More recent pipelines have incorporated some environmental protection and some rehabilitation but the low value of the desert land, the high cost of revegetation, and the lack of money for enforcement and supervision has often led to neglect and minimal treatment.

The impacts of linear structures can extend far beyond the boundaries of the immediate disturbance. Schlesinger and others (1989) studied the effects of diversion structures (earthen dikes) along the Colorado River Aqueduct on plants and soil. The structures were constructed to prevent runoff due to precipitation from washing sediments into open portions of the canal. Large areas downslope of the diversion structures received only incident precipitation, with essentially no runoff from the extensive drainages in the uplands

above the diversion structures. As a result, large areas of desert habitat on the downslope side of the diversion structures had a lower biomass of perennial and annual plants in comparison to adjacent areas with no diversion structures.

Garland and Bradley (1984) observed that some species of rodents in the Mojave of Nevada are more abundant near highways, while others are not. However, reduced abundance may have been an artifact of natural habitat heterogeneity since no mortality was observed during the 11-month study. Another effect of roads is edge enhancement in which perennial shrubs along roadsides are denser, larger, more vigorous, and support greater numbers of foliage arthropods than those away from roadsides (Vasek and others 1975b, Lightfoot and Whitford 1991). Johnson and others (1975) noted that primary productivity, as measured by standing crop, at study sites in the Mojave Desert of California increased about 17 times on the basis of vegetated area alone and 6 times when the area of the bare road surface was included as part of the productive unit. Unpaved roads showed increases of 6 and 3 times, respectively, in each category. Increased water availability from pavement runoff and increased retention of moisture under the pavement are probably responsible for the observed increase in plant vigor, although removal of competing plants that formerly occupied the roadway may confer an advantage to plants along the berm (Vasek and others 1975a). The increase in vigor attracts herbivorous insects (Lightfoot and Whitford 1991).

The effects and recovery of linear corridor construction in deserts have been studied by several researchers. The process of natural recovery, following powerline construction in the Sonoran Desert starts immediately with invasion by pioneering annual species, but perennial species may not return for over five years. The density and diversity of annual species may increase in comparison with undisturbed sites, perhaps due to the removal of large woody species (Hessing and Johnson 1982). An effect that is apparently linked to changes in plant abundance and composition is a reduction in the density, but not the community composition, of arthropods following establishment of access roads for powerline construction (Johnson and others 1983).

In the Mojave Desert, plant cover also increases following powerline construction. The rate of increase and composition of colonizing species varies considerably, confounding the ability to predict succession relative to adjacent undisturbed areas. Ground cover of short-lived perennial species increases in areas of severe disturbance, under the central wires, and along the edge of maintenance roads. After 33 years there was a noticeable, but not complete, recovery of predisturbance vegetation (Vasek and others 1975b). Natural revegetation (0–41% ground cover) by long-lived perennials has been observed 12 years after construction of a pipeline by trenching, piling, and refilling (Vasek and others 1975a). Disturbed and control areas appear to have similar cover, biomass, and densities of vegetation following partial recovery, but similarities disappear when the proportions of long-lived and dominant species are compared (Lathrop and Archbold 1980a,b). Species with these characteristics are not well represented on disturbed sites.

Management strategies for minimizing the effects of linear corridor construction include: placement of power poles closer to existing access roads, modifying construction techniques for buried pipelines, less frequent road grading, and limiting the width of motorcycle race corridors along powerlines (Artz 1989). Lathrop and Archbold (1980b) proposed several recommendations for routing corridors to minimize environmental impacts including: (1) routing them through gently sloping areas to minimize erosion, (2) routing them through areas occupied by colonizing species such as cheesebush (*Hymenoclea salsola*), (3) avoiding areas dominated by high nitrogen fixation communities such as cat's claw acacia (*Acacia greggii*), and (4) avoidance of undue soil compaction with implementation of soil loosening efforts to aid natural revegetation. Revegetation of linear corridors was evaluated by Kay (1979, 1988), Graves and others (1978), and Brum and others (1983).

The slow recovery of the desert to linear corridor impacts is perhaps best demonstrated by the visibility of many of the old Native American trade routes. Long-term use by foot traffic alone was sufficient to compact the soil and recovery after several hundred years has not been enough to hide these trails (personal observation).

Mining

Mining has been an important activity in the California desert since the late 1880s. Mining communities such as Kokoweef, Hart Mountain, Boron, Johannesburg, and many others have had mostly localized impacts on the desert. The most obvious forms of degradation are pits, ore dumps, and tailings, but the once-great demand for fuel and timber, grazing, and road building associated with mines was unquestionably more important in the past. Fugitive dust and toxic tailings are a more recent concern from some of these mining areas.

The Bureau of Land Management (1980) estimated that 12,545 ha in the California Desert Conservation

Area had been affected by major mining operations. If the many small prospects and adits are included, the area affected by mining would certainly be larger. The brine evaporation and dry lake mine operations are extensive and lead to substantial wind erosion (Wilshire 1983). Another problem is animal mortality at poorly managed cyanide extraction gold mines in the Mojave Desert (Clark and Hothem 1991, Henny and others 1994).

Military Training Operations

Large areas of the California desert have been impacted by temporary and ongoing military activities. Major training exercises included activities by General Patton in the early 1940s, the Desert Strike operation in 1964, and Bold Eagle in 1976. Between 1942 and 1944 more than a million soldiers passed through these training facilities, which covered more than 46,800 square km (Bureau of Land Management, 1990). The camps were effectively small cities, up to 2800 ha in size (e.g., Camp Granite) (Prose and Metzger 1985). Continuing impacts are generated by active military bases including the National Training Center (at Fort Irwin, the Marine Corps Air Ground Combat Center at Twentynine Palms, China Lake Naval Air Weapons Station, and the Chocolate Mountain Aerial Gunnery Range (Lathrop 1983a). Military operations cause intensive damage in many areas but also provide protection of thousands of hectares from other sources of disturbance by prohibiting public access. At Fort Irwin alone, the area in need of remediation is estimated to exceed 50,000 ha.

The recovery of large areas of the eastern Mojave Desert subjected to military training exercises almost 36 years earlier was studied by Lathrop (1983b). Impacted areas included tent sites, roads, and tank tracks. All impacted areas exhibited significant reductions in plant density and cover relative to control areas. Reductions of cover and density were greatest in tank tracks and least in tent areas. Recovery to predisturbance levels of cover and density varied according to disturbance type. Tent areas showed the greatest recovery, and roadways showed the least, reflecting the intensity of disturbance. Recovery in tank tracks was intermediate. Diversity of dominant perennials also varied between disturbed and nondisturbed areas but results were clouded by low species richness at the study sites and small sample sizes of the subdominants. However, diversity in disturbed transects at the Camp Ibis study site was low relative to control sites. Species similarity decreased between control and disturbed transects with increased disturbance and use intensity.

Similar observations and conclusions were reached by Prose and Metzger (1985) and Prose and others (1987) at abandoned military camps in the eastern Mojave. Long-lived species such as *Larrea tridentata* were dominant in all control areas but percentage cover and density were reduced in impacted areas. Dominant plants in disturbed areas included pioneer species such as *Ambrosia dumosa* and *Hymenoclea salsola*. Percentage cover values for pioneer species in disturbed areas were equal to or greater than control values.

Differences in vegetative structure between control and impacted plots were due to soil compaction, changes in soil texture, removal of the top layer of soil, and alteration of drainage channel density (Prose and others 1987). Penetrometer measurements show that a single pass by a ‘‘medium’’ tank can increase average soil resistance values by 50% relative to adjacent untracked soil in the upper 20 cm, but values of up to 73% were recorded. Dirt roadways could not be penetrated with a penetrometer below 5–10 cm due to extreme compaction. Physical modifications to the soil beneath tank tracks extended vertically to a depth of 25 cm and outward from the track edge to 50 cm (Prose 1985).

Recovery times to predisturbance levels of density and cover were estimated by Lathrop (1983b) assuming linear rates (Table 1). Recovery to predisturbance species composition would require much longer, if it were to occur at all. Areas receiving the greatest amount of soil compaction, such as roadways, require the longest recovery times. Tank tracks and tent areas recover in a shorter amount of time. Overall, recovery in plant density is slow relative to increases in cover. In other words, the number of individuals changes little following recovery from disturbance, but surviving individuals cover larger areas. A major conclusion from Lathrop’s study was that recovery to some original level of community composition and stability may not occur in the foreseeable future. However, recovery of comparable disturbed areas has been excellent on restoration test plots at the Marine Corps Air Ground Combat Center near Twentynine Palms, California (Zink personal communication).

Off-Road Vehicles

Off-road vehicle (OHV) use is one of the major recreational activities in the deserts of California. The Motorcycle Industry Council estimated that 4.7 million motorcycles were used by 11.7 million people in 1978 for off-highway recreation in the United States, a figure that does not include dune buggies and four-wheel drive vehicles (Kockelman 1983).

The impacts of OHVs have been well documented (Webb and Wilshire 1983) and include destruction of soil stabilizers (see section on biotic components of soil), soil compaction, reduced rates of water infiltra-

tion, increased wind and water erosion, noise, decreased abundance of lizard populations (Busack and Bury 1974), and destruction of vegetation (Vollmer and others 1976). Compaction of a desert soil reduces the root growth of desert plants and makes it much harder for seedlings to survive (Bainbridge and Virginia 1990, Bainbridge and others 1995a). An excellent review of the effects of OHVs in the Mojave and other deserts is contained in Webb and Wilshire (1983) and the reader is referred to that document for information beyond that presented herein.

Soil compaction is a common effect of any compressive action on most soils. Compaction results from a variety of factors other than OHV use, including trampling by grazers, human trampling (Liddle 1991, 1997), and even raindrops (see review in Webb 1982). In the case of OHVs, compaction occurs at shallow depths related to the geometry of the contact surface between the tire and the soil interface. In one study the greatest increase in soil density occurred at a depth of 30–60 cm after being compacted by a motorcycle (Webb 1983). Soil density increases as a function of the number of vehicle passes, while soil infiltration rate decreases. Soils that are most susceptible to compaction are loamy sands and coarse gravelly soils with variable particle sizes. Wet soils are more susceptible to compaction than dry soil. Soils that are least affected include sands and clays.

Another by-product of heavy OHV use is increased wind and water erosion. The degree of erosion experienced in an area exposed to OHV use is affected by two main factors. First, increased water erosion is partially attributable to decreased infiltration rates due to compaction. Second, OHVs destroy surface stabilizers (see section on biotic components of soil), making soils more susceptible to erosion (Hinkley and others 1983). The enormity of the problem in the Mojave Desert is underscored by the fact that satellite photos revealed six dust plumes covering over 1700 square km of the western Mojave on 1 January 1973 that were attributed to surface destabilization primarily by OHVs (Nakata and others 1976, Gill 1996).

As shown in numerous photographs in Webb and Wilshire (1983), the effects of erosion can have indirect effects, since debris flows (Nakata 1983) can bury plants at some distance from the impacted area. Areas that are least susceptible to water and wind erosion following OHV use are dunes, playas, and areas with abundant coarse surface material (Gillette and Adams 1983, Hinckley and others 1983). Restoration of OHV areas affected by erosion requires actions to not only stop continuing erosion (Harding 1990, Heede 1983, Middleton 1990), but also action to restore past damage.

Desert soils vary in their susceptibility to OHV damage. Susceptibility is generally high in all areas except barren sand dunes (but see Bury and Luckenbach 1983), and the clay flats of playas. Soil damage caused by OHVs is environmentally significant due to the fact that desert soils may take 10,000 years to develop (Dregne 1983). From this estimate, Dregne concluded that it was futile to speak of disturbed soil recovery in time frames related to human occupancy.

Another major effect of OHV use is the destruction of plants. Lathrop (1983a) examined aerial photographs of nine disturbed and undisturbed areas in the Mojave Desert to assess the effects of OHV usage. Perennial plant density and cover were dramatically reduced in OHV areas. The percentage of cover and / or density in OHV-impacted areas relative to control areas was less than 15% in three of the sites examined. Destruction of plants resulted not only from crushing stems and foliage, the extensive root systems that fill the intershrub spaces, and germinating seeds, but also from the superstructure of the vehicle. The latter factor is important since it is responsible for plant destruction in an area wider than the track width of the vehicle. The wheel tracks of a full-size off-road vehicle operating in an undisturbed area can damage almost 0.5 ha of land with every 6.44 km traveled. Support vehicles, including very large and heavy motor homes, are very destructive, and camping areas are especially hard hit.

An easily detected but poorly understood effect of OHVs is noise. Noise from certain types of OHVs can reach 110 decibels, which is near the threshold of human pain. Brattstrom and Bondello (1983) demonstrated that OHV use in the Mojave Desert caused noise levels that caused hearing loss in animals such as kangaroo rats, desert iguanas, and fringe-toed lizards; interfered with the ability of kangaroo rats to detect predators such as rattlesnakes; and caused unnatural emergence of spadefoot toads that were estivating until the arrival of rain for breeding, a situation that could result in death. The authors noted that although OHVs are not the loudest source of human-generated sound in the Mojave, they occur more frequently than any other high-intensity sound source. In their report, Brattstrom and Bondello recommended that OHV areas be located away from the ranges of ''all undisturbed desert habitats, critical habitats, and all ranges of threatened, endangered, or otherwise protected desert species.''

The impact of OHV use on desert tortoises in the Mojave Desert of California was examined by Bury and Luckenbach (1986) in an unpublished report. Significantly more tortoises and active burrows were found on a 25-ha control plot than on a similar plot exposed to OHV use. In addition, subadult and adult tortoises on

the control plot exhibited larger body mass than those on the OHV plot.

Impacts related to OHV use present a serious challenge to desert restoration projects for three reasons: (1) the potentially severe impact of OHV use in desert ecosystems, (2) the widespread nature of the OHV impacts in the California desert, and (3) the fact that OHV areas are often located in or near environmentally sensitive habitats. Areas targeted for restoration should be closed to OHV use prior to initiating procedures to ameliorate past damages.

Invasive Plants

Invasive exotic plants have had a significant impact on the natural communities of California (Mooney and others 1986, Rejmánek and Randall 1994), including the southern California desert ecosystem. Invasion has been facilitated by habitat disturbances that allow exotic species to colonize habitats once dominated by native species (Hunter and others 1987). Once established, exotic plants may diminish the abundance of native species due to competitive interactions or by disruption of natural processes such as fire frequency and intensity.

Some of the more important exotic plants in the southern California desert are saltcedar (*Tamarix ramosissima*), also known as tamarisk (Lovich and de Gouvenain 1998), Russian thistle (*Salsola iberica*) (Young 1991), filaree (*Erodium cicutarium*), and several grass species including split grass (*Schismus* spp.) and bromes (*Bromus* spp.) (Brown and Minnich 1986, Hunter 1991). Immense areas of desert are colonized by these species. Although other exotic plants are present in the Mojave Desert, these are important because of their ubiquity.

Exotic plants present two major problems to the integrity of the desert ecosystem. First exotic annuals increase the fuel load and frequency of fire in a community that is poorly adapted to fire. Second, some exotic plants exhibit allelopathic effects that negatively affect native species, especially annuals. Negative interactions have been demonstrated between Russian thistle and other species in the laboratory (Allen 1982a, Lodhi 1979). In addition, competition of Russian thistle with native perennial grasses increases under drought conditions (Allen 1982b), furthering establishment of the exotic. Fortunately, Russian thistle competes poorly with established vegetation and rarely supplants well-established native populations. Unfortunately, once the soil is disturbed and native plants are eliminated, Russian thistle gains a strong foothold (Young 1991). General reviews of the threats posed by exotic species invasions in native ecosystems are summarized by Cheater (1992) and D'Antonio and Dudley (1993).

Air Pollution

One of southern California's most famous exports is smog. While most noticeable in the inland valleys of the state, smog is often transported via atmospheric processes into the Mojave Desert (Pryor and Hoffer 1991). Anthropogenic pollutants include ozone, sulfur dioxide, and various particulates. Atmospheric tracer experiments have shown that pollutants released in the San Fernando Valley impact the southern Mojave Desert towns of Adelanto and Palmdale, while those released in the southern San Joaquin Valley impact the northern Mojave Desert towns of Mojave and China Lake (Reible and others 1982). Experimental tracers used in atmospheric transport studies are diluted by factors of only 2–3 during passage between source and receptor areas. Impacts are maximized during evening and nighttime hours, independent of the time of release in the San Joaquin Valley, because of the diurnal mountain–valley wind cycle. Ozone levels in the Mojave Desert can exceed 100 parts per billion (ppb) or more when offshore wind transports atmospheric pollutants from the Los Angeles Basin (Thompson and others 1984a). By comparison, ozone levels in remote areas range from 20 to 40 ppb.

The most obvious effect of smog in the Mojave Desert has been visibility degradation in an area historically distinguished by extraordinary visibility (Walsh and Hoffer 1991). Median visibility is 48–88 km in large urban areas and 104–128 km in nonurban locations. Visibility has decreased 10%–30% from the middle of the 1950s to the early 1970s at many recording stations (Trijonis 1979).

Much of the visibility loss is related to particulates, including nitrogen-rich compounds. Dryfall of these compounds from air pollution can be a major source of supplemental N for plants. This favors many exotic plant species over native annuals and perennials. Wedin and Tilman (1996) found that half the native plant species in a Minnesota grassland were lost from the community at supplemental N levels mimicking dryfall deposition rates.

A less obvious effect is damage to plants. Stolte (1991) observed injurious effects to desert plants exposed to ozone and sulfur dioxide in laboratory experiments. Annual plant species of the genera *Camissonia* and *Cryptantha* exhibit high sensitivity to both gases. The grass *Oryzopsis hymenoides* exhibits high sensitivity to sulfur dioxide, as do some types of cryptogamic soils. Responses of cryptogamic soils include increased electrolyte leakage, chlorophyll degradation, and reduced nitrogen fixation (Belnap 1991).

Studies of plants from the Mojave and Colorado Deserts show that perennial species vary in their re-

Figure 2. The effects of fire in the desert are obvious in this photo taken near Palm Springs, California, about five years after the blaze. Note the almost complete elimination of perennial shrubs in the burned area to the left. Perennial plant species in the Mojave and Colorado Deserts are long-lived and very sensitive to fire, traits that collectively contribute to the long recovery times typical of many desert plant communities after fire. Photo by Jeff Lovich.

sponse to SO_2 and NO_2. *Larrea tridentata* is sensitive to fumigation by these pollutants under experimental conditions, displaying extensive leaf injury and reduced growth or dry weight. *Encelia farinosa* and *Ambrosia dumosa* show intermediate responses, while *Atriplex canescens* appears to be resistant (Thompson and others 1980). Sensitivity also varies among native annual plants, with *Camisonia claviformis, C. hirtella,* and *Cryptantha nevadensis* exhibiting leaf injury at low concentrations of SO_2 and O_3 (Thompson and others 1984b).

Fisher (1978) suggested that high rates of mortality in desert holly (*Atriplex hymenelytra*) in the northern Mojave Desert (Death Valley) were related to elevated ozone levels. During the summer months he recorded ozone levels that were twice the national standard of 0.08 ppm. Photosynthesis and water use was significantly reduced in greenhouse experiments where seedlings were exposed to 0.15–0.18 ppm ozone for 3 h. Ozone-induced reduction in water-use efficiency was postulated to be the cause of declining *Atriplex* populations in Death Valley.

Additional summaries of the impacts of air pollution in the Mojave and Colorado Deserts are provided by Mangis and others (1991), Thompson (1995), and VanCuren (1995).

Anthropogenic Fire

Fire was not an important factor in shaping the prehistoric structure and dynamics of plant communities in the California desert. The infrequency of fire in the prehuman landscape of the desert was due to limited biomass, large intershrub spacing, low combustibility of some native plants, sparse groundcover to support and propagate combustion, and the absence of human-mediated fire suppression activities (Humphrey 1974, O'Leary and Minnich 1981, Minnich 1983, Brown and Minnich 1986). Such is not the case in other desert and semidesert areas of the American Southwest, including parts of the Sonoran and Chihuahuan deserts, where fire was an important prehistoric agent in maintaining grassland seral stages (Humphrey 1958, 1963, 1987, Reynolds and Bohning 1956).

The proliferation of exotic annual plant species such as *Bromus, Schismus,* and *Salsola* has dramatically increased the fuel load and frequency of fires in many ecosystems around the world (D'Antonio and Vitousek 1992), including parts of the California desert (O'Leary and Minnich 1981, Brown and Minnich 1986), in recent years. The frequency of fires in the Colorado Desert of California is further enhanced by the proximity of previously burned areas (Chou and others 1990). Native perennial shrubs are poorly adapted to relatively low-intensity fires as evidenced by low rates of recovery (Figure 2). In the upper Coachella Valley on the east scarp of the San Jacinto Mountains near Palm Springs, California, burned creosote bush scrub is replaced by open stands of *Encelia farinosa,* native ephemerals, and exotic species such as *Schismus* and *Bromus* (Brown and Minnich 1986).

Postfire vegetational recovery along a chaparral–desert ecotone including parts of Anza-Borrego Desert State Park in San Diego County, California was examined by Tratz and Vogl (1977). They observed high recovery (as measured by speed of resprouting) in chaparral shrubs and desert-wash plants, but low recovery in cacti. Herbivorous mammals present before the burn were also present afterwards, since rapid recovery of shrubs provided adequate food supplies for wildlife, even in the first months after the fire. If California desert perennial plant communities are not well adapted

to fires, animals that coevolved in the ecosystem should not be expected to respond favorably to fire either.

According to fire personnel at the California Desert District (CDD) Office of the Bureau of Land Management (BLM), the CDD (including the Mojave and Colorado Deserts) had a ten-year average of 175 fires per year prior to 1992 (range 100–475) that affect an average of 10,927 ha annually (range 607–34,400 ha). The CDD estimates include a very small amount of BLM land outside the desert.

Impacts on Biotic Components of Soil: The Invisible Component of Biodiversity

Although emphasis is often placed on the physical and chemical properties of various soils, they contain important biotic components as well including: soil surface stabilizers such as algae and lichens, nematodes and other metazoans, various bacteria, and mycorrhizae. Odum (1994) referred to these organisms as the invisible component of biodiversity. While not as conspicuous as macrofloral elements, biotic components of soil are important symbionts that are easily destroyed by certain human activities.

Undisturbed desert areas are characterized by the presence of soil stabilizers, including lichen, fungal, bacterial, and algal crusts; desert pavement; mechanical crusts; and chemical crusts. The biotic components of these stabilizers are collectively referred to as cryptobiotic soil. Mineral-derived crusts form under a variety of physical and chemical conditions that may actually be facilitated by biotic components (Elvidge and Iverson 1983, Taylor-George and others 1983). Soil stabilizers are important agents in preventing erosion but are easily disturbed since they occur at the surface. Stabilization mechanisms include binding soil particles with thallial filaments in the case of biotic stabilizers, armoring the surface, and increasing surface roughness. Crusts also provide germination sites for vascular plants (but see Wood and others 1982), and conserve water (see review in Cole 1990). The susceptibility of crusts to damage varies according to the composition of the underlying soil. In soils subjected to large shear stresses, a single pass by a vehicle is capable of destroying well-developed crust. When the forces are mainly compressive, crusts can survive a single pass in a slightly modified form; however, OHV use is capable of quickly eliminating crusts in an impact area (Wilshire 1983).

Considerable research has been conducted on the impacts of grazing and other agents of trampling on cryptobiotic soil crusts. These crusts are very important not only because of the soil-stabilization functions mentioned above, but because they facilitate the accumulation of organic material and soil nutrients, particularly nitrogen in the upper layers of soil (Kleiner and Harper 1977, Johansen 1993), and enhance soil moisture retention (Belnap and Gardner 1993). Research in desert and semidesert areas in Utah and Arizona has consistently shown that cryptobiotic soil is heavily impacted by grazing, even light winter grazing (Kleiner and Harper 1977, Anderson and others 1982, Brotherson and others 1983). Impacts include the destruction of surface pinnacles associated with development of cryptogamic soils (Anderson and others 1982) and the virtual obliteration of biotic elements (Cole 1990). Lichens and mosses are most sensitive to disturbance, with algal components being more resilient (Brotherson and others 1983).

Cole (1990) conducted an interesting experiment at Grand Canyon National Park to examine the effect of trampling by hikers wearing lug-soled boots. Only 15 passes were required to destroy crusts. Visual evidence of biotic components was reduced to near zero after 50 passes. The results of Cole's experiment clearly illustrate the fragility of crusts to trampling.

Cryptobiotic soil recovery may require long time intervals without intervention. Following exclusion of grazing in a Utah semidesert study site, cryptobiotic cover increased from 4%–15% in 14–18 years, but only 1% per year for the next 20 years (Anderson and others 1982). Cole (1990) observed partial recovery from human trampling in one to three years and extensive recovery after five years. However, surface irregularities associated with well-developed cryptogamic cover remained low even after five years, suggesting that recovery was incomplete. Belnap (1993) noted that over 250 years may be required for full recovery on the Colorado Plateau. Recovery was improved but was still very slow when scalped experimental plots were inoculated with crusts from surrounding areas. In the northern Mojave Desert, lichen crusts may not reoccupy heavily disturbed areas even after 63 years (Wilshire 1983). Details of the formation and recovery of chemical and mechanical crusts are discussed in detail by Wilshire (1983). The nitrogen-fixation capabilities of damaged soil may take over 50 years to recover (Belnap 1995).

Important symbiotic relationships have developed between certain species of vascular plants and vesicular–arbuscular mycorrhizal (VAM) fungi and rhizobia. The small-diameter hyphae of symbiotic fungi serve as energy efficient root hairs, enabling the host plant to better absorb nutrients, particularly phosphorus (Bloss 1985) and water (Bethlenfalvay and others 1984). Rhizobia are bacteria capable of fixing atmospheric nitrogen for use by plants. The importance of VAM fungi in desert plant communities is underscored by the fact

that in a recent survey of 38 plant species (19 families) in Anza-Borrego Desert State Park in the Colorado Desert of California all were colonized by VAM species (Bethlenfalvay and others 1984). Plants naturally associated with VAM that are also found in the western Mojave Desert include *Hymenoclea, Ambrosia, Opuntia,* and *Larrea.* Bloss (1985) reported numerous plant associations in the Sonoran Desert of Arizona as well.

Previous studies have demonstrated the importance of maintaining and enhancing soil microbes in restoration projects (St. John 1984, Bainbridge 1990). Establishing plants in disturbed areas with marginal soils may be difficult or impossible without the presence of a vigorous population of microbial symbionts. These symbionts are adversely affected by soil compaction. Studies have shown 1–2 m of hyphae per gram of soil in Mojave and Sonoran soils, yet virtually none in disturbed areas (Zink personal communication). Restoration is complicated by the fact that fertilizers can inhibit mycorrhizae growth.

Can the Desert Be Restored?

Plant growth and establishment are naturally slow under the extreme conditions of the desert, and disturbance makes these conditions even more severe (Bainbridge 1990). Disturbance typically reduces both the infiltration of water into the soil and the moisture-holding capacity of the soil (Bainbridge and Virginia 1990). This increases the value of rapid deep root growth, which is made more difficult by increases in soil strength from compaction and reduced soil moisture. These synergistic effects make plant establishment much more difficult after disturbance. Revegetation and restoration work can help mitigate many of these impacts and speed recovery, but the severe conditions and unpredictable rainfall still make restoration of these sites very challenging.

A brief history of revegetation studies in the deserts of California was provided by Kay and Graves (1983). Studies in the Mojave Desert are few and relatively recent. One of the earliest studies evaluated the success of revegetation efforts along the second Los Angeles Aqueduct (Kay 1979, 1988). Construction involved stripping the vegetation from an area 200 km long × 60 m between 1968 and 1970. The seeds of seven species of native plants were distributed at six 2- to 15-ha sites on the aqueduct. The seeds of all but one species, *Atriplex polycarpa,* were from local stock. Surface preparation involved ripping the soil to 25 cm on 60-cm centers to relieve compaction. A rangeland drill was used to set the seeds at a depth of about 1 cm. Success varied among plant species. *Ambrosia dumosa* exhibited good establishment on three of six sites, but only one site had numbers approaching that of adjacent undisturbed areas. *Larrea tridentata* exhibited similar results. The other species, including *Atriplex polycarpa, Ephedra nevadensis, Hymenoclea salsola,* and *Lepidospartum squamatum,* were totally unsuccessful. *Atriplex canescens* suffered as a result of heavy grazing. The most abundant shrub along the aqueduct, *Chrysothamnus nauseosus,* established itself naturally, although it was uncommon in adjacent undisturbed areas. Kay (1988) concluded that natural revegetation is good in many years and poor in others, while artificial seeding did not consistently hasten or improve plant recovery.

In another experiment along the aqueduct, Graves and others (1978) tested the effects of a single irrigation and the success of direct seeding versus transplanting. The two methods of establishment exhibited widely variable success rates from site to site and according to species, but were not enhanced by irrigation. Substrate characteristics may influence the success of irrigation as measured by the appearance of native winter annuals (Johnson and others 1978).

The overall success of the revegetation attempt along the aqueduct was low. The vast majority of the aqueduct was still a highly visible scar in the early 1980s (Kay and Graves 1983), but recovery was inhibited by grazing and OHV use. Conclusions from the study were that more attention should be focused on establishment of visually dominant species such as *Larrea tridentata,* seeding should take place as soon after disturbance as possible, areas should be protected from grazing and OHV use, and local seed stock should be utilized for all species.

Highway revegetation studies were also reviewed by Kay and Graves (1983). Survival of container-grown shrubs planted in October 1973 and February 1974 at a site in Mojave, California, was 90% in May 1974. The roots of the transplants were exposed after a heavy rain in December 1974, and all plants were dead by October 1975. *Atriplex* spp., *Chrysothamnus* spp., and *Ephedra* spp. exhibited the greatest survival. Success was limited by rabbit overgrazing and competition from Russian thistle (*Salsola*). Container plantings were more successful when planted in the late winter or early spring. Application of fertilizer encouraged both the invasion of native woody shrubs and the nonnative annual grass *Schismus arabicus.*

Others have experienced similar success in revegetation. Brum and others (1983) observed low, long-term seedling establishment for a variety of species under several irrigation treatments along a powerline transmission corridor. The overall germination–establishment rate for seedling and postseeding irrigation success was 0.3%, and 26% for transplanted seedlings. *Larrea* exhib-

ited poor germination under field conditions and responded poorly to all revegetation attempts.

More successful revegetation has been achieved at the Nevada Test Site in the northern Mojave Desert (Romney and others 1990). Greater than 80% survival of transplanted native shrubs and grasses was achieved when plants were protected from jackrabbits and irrigation was provided periodically.

Restoration efforts in the Colorado Desert of California were reviewed by Bainbridge and Virginia (1990). Although the plant communities differ somewhat between the Colorado and Mojave Deserts, both ecosystems pose similar challenges to restoration attempts: high temperatures, intense sunlight, limited moisture availability, high levels of herbivory by rodents and rabbits, and low soil fertility. Much of the success in revegetation experiments in the Colorado Desert is due to efforts to protect plants from herbivores and the use of buried water reservoirs for irrigation. Direct seeding attempts have generally been unsuccessful relative to transplants. *Larrea tridentata*, in particular, responded well to transplanting, especially if pruned prior to planting to increase the root-to-shoot ratio.

Assessing the nature and magnitude of human-induced disturbances makes restoration planning more efficient by enabling limited resources to be directed at critical problems. Ongoing studies (Bainbridge and others 1995a,b) of the effectiveness of desert restoration techniques are steadily advancing our ability to rehabilitate degraded arid lands in the southwestern United States, and the reader is referred to these references for details beyond the brief overview given in this section.

Plant recovery usually requires container-planting activities as well as site improvement. The most common method of direct seeding is simple hand seeding, which allows species to be matched to specific site conditions, appropriate planting depths, and results in a more natural appearance than machine planting. However, limited rainfall and removal of seeds by rodents and harvester ants may severely limit seedling establishment during typical years.

Transplanting is increasingly being used to provide nurse and seed plants for the disturbed areas (Bainbridge and others 1995b). The dominant shrubs and trees of the Colorado Desert are relatively easy to grow in a nursery or maintained landscape setting, and they are well adapted to transplanting with after-care. They are more challenging to establish in the field in a low- or no-maintenance situation, although once established, growth rates can be high. Reestablishment of annuals has been more difficult. New containers and soil mixes have improved plant survival. Deep pipe and buried pot irrigation and hand watering have also been effective. Tree shelters to limit herbivory and wind damage are also important.

A full appreciation of the ecological setting and adaptation of desert plants can make establishment less costly and more successful, but it is still expensive. The cost of restoring road edge areas in Joshua Tree National Park is fairly well established (after almost 10 years of work) and runs up to $15,000 per ha to establish large potted perennials in areas that are easily accessed. The cost of duplicating this type of work at remote sites would be much higher. Research conducted by colleagues at San Diego State University has emphasized lower-cost, less-intensive restoration, but the costs (excluding research) are still on the order of $12,000–25,000 / ha. Even these high project costs provide no guarantee of success.

Conclusions

Desert areas disturbed by human activities may take centuries to recover without active intervention. Undisturbed desert soils are often in a relatively stable equilibrium developed over hundreds or thousands of years. Removal of vegetation and disturbance of soil crusts or soil structure can destroy this equilibrium, leading to wind and water erosion that are very difficult or impossible to control without very high investments in material and labor.

One of the key lessons of our research in the Mojave and Sonoran deserts is the critical importance of minimizing the intensity, frequency, and area of disturbance. Past research summarized in this paper has identified the wide range of effects from human disturbance and the difficulty and the high cost of mitigating damage. While recovery rates can be increased with modest expenditures, a major restoration program to improve recovery for just the OHV-damaged areas in the California desert region could exceed one billion dollars. Available funding will permit only a limited restoration for selected sites, even with continuing generous contributions of volunteer labor. Fences, signs, and enforcement to prevent further damage may often be a better investment than intensive restoration.

Recent research in the Mojave Desert demonstrates the benefits that protection can impart, even to previously disturbed areas. Brooks (1995) conducted a comparison between the Desert Tortoise Research Natural Area (DTNA) and unprotected land immediately adjacent. The DTNA was fenced to prohibit both OHV use and sheep grazing between 1978 and 1979. By the time of his study in 1990–1992, Brooks demonstrated that aboveground live annual biomass was generally greater

inside than outside the fenced area, with the exception that the exotic annual grass *Schismus barbatus* produced more biomass outside the fenced area. Percent cover of perennial shrubs, seed biomass, and rodent density and diversity were also greater inside the fenced area.

To be successful, revegetation and restoration require careful attention to ecological relationships, both above and below ground, herbivory, soil characteristics, microclimate, and patterns of moisture availability (Bainbridge 1990, Bainbridge and others 1995a). Undoing the damage done to the soil system by disturbance is a critical step toward recovery and restoration. In general, strategies that recreate or mimic natural conditions are most likely to speed recovery of the entire ecosystem.

Research conducted in the Mojave and Colorado desert ecosystem has important applications for the American Southwest and throughout the world's arid zones. These areas have deteriorated rapidly under pressure from overgrazing, poor farming, and removal of trees and shrubs for fuelwood. The lessons learned in the desert ecosystem of southern California may help people living in these areas to protect or restore the productivity of their lands, and improve their lives.

Acknowledgments

We gratefully acknowledge the following people for their assistance and comments during the preparation of this manuscript: Hal Avery, Kristin Berry, Bill Boarman, David Cole, Richard Franklin, June Latting, Michael Liddle, Mike Mitchell, and Howard Wilshire. Research was supported by a grant from the California Department of Parks and Recreation, Off-Highway Motor Vehicle Recreation Division. This paper is dedicated to the memory of June Latting.

Literature Cited

Allen, E. B. 1982a. Germination and competition of *Salsola kali* with native C3 and C4 species under three temperature regimes. *Bulletin of the Torrey Botanical Club* 109:39–46.

Allen, E. B. 1982b. Water and nutrient competition between *Salsola kali* and two native grass species (*Agropyron smithii* and *Bouteloua gracilis*). *Ecology* 63:732–741.

Anderson, D. C., K. T. Harper, and S. R. Rushforth. 1982. Recovery of cryptogamic soil crusts from grazing on Utah winter ranges. *Journal of Range Management* 35:355–359.

Anonymous. 1991. Society for Range Management: desert tortoise report. *Renewable Resources Journal* 9:30.

Archer, S., and F. E. Smeins. 1991. Ecosystem-level processes. Pages 109–139 *in* R. K. Heitschmidt and J. W. Stuth (eds.), Grazing Management an Ecological Perspective. Timber Press, Portland, Oregon.

Artz, M. C. 1989. Impacts of linear corridors on perennial vegetation in the East Mojave Desert: implications for environmental management and planning. *Natural Areas Journal* 9:117–129.

Bainbridge, D. A. 1990. The restoration of agricultural lands and drylands. Pages 4–13 *in* J. J. Berger (ed.), Environmental restoration: science and strategies for restoring the earth. Island Press, Washington, DC.

Bainbridge, D. A., and R. A. Virginia. 1990. Restoration in the Sonoran desert of California. *Restoration and Management Notes* 8:3–13.

Bainbridge, D. A., R. McAller, M. Fidelibus, R. Franson, A. C. Williams, and L. Lippitt. 1995a. A beginners guide to desert restoration. National Park Service, Denver Service Center, 34 pp.

Bainbridge, D. A., M. Fidelibus, and R. McAller. 1995b. Techniques for plant establishment in arid ecosystems. *Restoration and Management Notes* 13:190–197.

Balph, D. F., and J. C. Malecheck. 1985. Cattle trampling of crested wheatgrass under short-duration grazing. *Journal of Range Management* 38:226–227.

Belnap, J. 1991. Sensitivity of desert cryptogams to air pollutants: soil crusts and rock lichens. Pages 112–119 *in* D. Mangis, J. Baron and K. Stolte (eds.), Acid rain and air pollution in desert park areas. National Park Service, United States Department of the Interior.

Belnap, J. 1993. Recovery potential of cryptobiotic crusts: inoculant use and assessment methods. *Great Basin Naturalist* 53:89–95.

Belnap, J. 1995. Surface disturbances: their role in accelerating desertification. *Environmental Monitoring and Assessment* 37:39–57.

Belnap, J., and J. S. Gardner. 1993. Soil microstructure in soils of the Colorado Plateau: the role of the cyanobacterium *Microcoleus vaginatus*. *Great Basin Naturalist* 53:40–47.

Bentley, H. L. 1898. Cattle ranges of the southwest: a history of the exhaustion of the pasturage and suggestions for its restoration. US Department of Agriculture, Farmers Bulletin 72, pp. 1–31.

Bethlenfalvay, G. J., S. Dakessian, and R. S. Pacovsky. 1984. Mycorrhizae in a southern California desert: ecological implications. *Canadian Journal of Botany* 62:519–524.

Bloss, H. E. 1985. Studies of symbiotic microflora and their role in the ecology of desert plants. *Desert Plants* 7:119–127.

Boarman, W. I. 1993. When a native predator becomes a pest: A case study. Pages 191–206 *in:* S. K. Majumdar, E. W. Miller, D. E. Baker, E. K. Brown, J. R. Pratt, and R. F. Schmalz (eds.), Conservation and Resource Management. The Pennsylvania Academy of Science, Easton, Pennsylvania.

Boarman, W. I., and M. Sazaki. 1996. Highway mortality in desert tortoises and small vertebrates: success of barrier fences and culverts. Pages 169–173 *in* G. J. Evink, P. Garrett, D. Zeigler, and J. Berry (eds.), Trends in addressing transportation related wildlife mortality. Proceedings of the transportation related wildlife mortality seminar. Environmental Management Office, Department of Transportation, Tallahassee, Florida.

Borman, M. M., and D. E. Johnson. 1990. Evolution of grazing and land tenure policies on public lands. *Rangelands* 12:203–206.

Bostick, V. 1990. The desert tortoise in relation to cattle grazing. *Rangelands* 12:149–151.

Bowers, J. E., R. H. Webb, and R. J. Rondeau. 1995. Longevity, recruitment and mortality of desert plants in Grand Canyon, Arizona, USA. *Journal of Vegetation Science* 6:551–564.

Bowers, J. E., R. H. Webb, and E. A. Pierson. 1997. Succession of desert plants on debris flow terraces, Grand Canyon, Arizona, USA. *Journal of Arid Environments* 36:67–86.

Brattstrom, B. H., and M. C. Bondello. 1983. Effects of off-road vehicle noise on desert vertebrates. Pages 167–206 *in* R. H. Webb and H. G. Wilshire (eds.), Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Brooks, M. L. 1995. Benefits of protective fencing to plant and rodent communities of the western Mojave Desert, California. *Environmental Management* 19:65–74.

Brotherson, J. D., S. R. Rushforth, and J. R. Johansen. 1983. Effects of long-term grazing on cryptogam crust cover in Navajo National Monument, Ariz. *Journal of Range Management* 36:579–581.

Brown, D. E., and R. A. Minnich. 1986. Fire and changes in creosote bush scrub of the western Sonoran Desert, California. *American Midland Naturalist* 116:411–422.

Brum, G. D., R. S. Boyd, and S. M. Carter. 1983. Recovery rates and rehabilitation of powerline corridors. Pages 303–314 *in* R. H. Webb and H. G. Wilshire (eds.), Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Bureau of Land Management. 1980. The California desert conservation area plan. US Department of the Interior, Riverside, California, 173 pp.

Burk, J. H. 1977. Sonoran desert. Pages 869–889 *in* M. G. Barbour and J. Major (eds.), Terrestrial Vegetation of California. John Wiley & Sons, New York.

Bury, R. B., and R. A. Luckenbach. 1983. Vehicular recreation in arid land dunes: biotic responses and management alternatives. Pages 207–221 *in* R. H. Webb, and H. G. Wilshire (eds.), Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Bury, R. B., and R. A. Luckenbach. 1986. Abundance of desert tortoises (*Gopherus agassizii*) in natural and disturbed habitats, Unpublished draft report, US Fish and Wildlife Service.

Busack, S. D., and R. B. Bury. 1974. Some effects of off-road vehicles and sheep grazing on lizard populations in the Mojave Desert. *Biological Conservation* 6:179–183.

Charley, J. L., and S. W. Cowling. 1968. Changes in soil nutrient status resulting from overgrazing and their consequences in plant communites of semi-arid areas. *Proceedings of the Ecological Society of Australia* 3:28–38.

Cheater, M. 1992. Alien invasion. *Nature Conservancy* September/October:24–29.

Chou, Y.-H., R. A. Minnich, L. A. Salazar, J. D. Power, and R. J. Dezzani. 1990. Spatial autocorrelation of wildfire distribution in the Idyllwild quadrangle, San Jacinto Mountain, California. *Photogrammetric Engineering and Remote Sensing* 56:1507–1513.

Clark, D. R., Jr., and R. L. Hothem. 1991. Mammal mortality at Arizona, California, and Nevada gold mines using cyanide extraction. *California Fish and Game* 77:61–69.

Cody, M. L. 1986. Spacing patterns in Mojave Desert plant communities: Near-neighbor analyses. *Journal of Arid Environments* 11:199–217.

Coe, M. 1990. The conservation and management of semi-arid rangelands and their animal resources. Pages 219–249 *in* A. S. Goudie (ed.), Techniques for desert reclamation. John Wiley & Sons, Chichester.

Cole, D. N. 1990. Trampling disturbance and recovery of cryptogamic soil crusts in Grand Canyon National Park. *Great Basin Naturalist* 50:321–325.

D'Antonio, C., and T. L. Dudley. 1993. Alien species. *Pacific Discovery* Summer:9–11.

D'Antonio, C. M., and P. M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. *Annual Review of Ecology and Systematics* 23:63–87.

Dregne, H. E. 1983. Soil and soil formation in arid regions. Pages 15–30 *in* R. H. Webb and H. G. Wilshire (eds.), Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Elvidge, C. D., and R. M. Iverson. 1983. Regeneration of desert pavement and varnish. Pages 225–243 *in* R. H. Webb and H. G. Wilshire (eds.) Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Field, T. G. 1990. The future of grazing on public lands. *Rangelands* 12:217–219.

Fisher, J. C., Jr. 1978. Studies relating to the accelerated mortality of *Atriplex hymenelytra* in Death Valley National Monument. Unpublished Masters thesis. University of California, Riverside.

Garland, T. J., and W. G. Bradley. 1984. Effects of a highway on Mojave Desert rodent populations. *American Midland Naturalist* 111:47–56.

General Accounting Office. 1992. Rangeland management: BLM's hot desert grazing program merits reconsideration. United States General Accounting Office. GAO/RCED-92-12, Washington, DC.

Genin, D., and A. Badan-Dangon. 1991. Goat herbivory and plant phenology in a Mediterranean shrubland of northern Baja California. *Journal of Arid Environments* 21:113–121.

Germano, D. J., and C. R. Hungerford. 1981. Reptile population changes with manipulation of Sonoran Desert shrub. *Great Basin Naturalist* 41:129–137.

Germano, D. J., and D. N. Lawhead. 1986. Species diversity and habitat complexity: does vegetation organize vertebrate communities in the Great Basin? *Great Basin Naturalist* 46:711–719.

Germano, D. J., R. Hungerford, and Martin S. Clark. 1983. Responses of selected wildlife species to the removal of mesquite from desert grassland. *Journal of Range Management* 36:309–311.

Gill, T. E. 1996. Eolian sediments generated by anthropogenic disturbance of playas: Human impacts on the geomorphic system and geomorphic impacts on the human system. *Geomorphology* 17:207–228.

Gillette, D. A., and J. Adams. 1983. Accelerated wind erosion and prediction of rates. Pages 97–109 *in* R. H. Webb and H. G. Wilshire (eds.), Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Gillis, A. M. 1991. Should cows chew cheatgrass on commonlands? *Bioscience* 41:668–675.

Graves, W. L., B. L. Kay, and W. A. Williams. 1978. Revegetation of disturbed sites in the Mojave Desert with native shrubs. *California Agriculture* March:4–5.

Harding, M. V. 1990. Erosion control effectiveness: Comparative studies of alternative mulching techniques. Pages 149–156 *in* J. J. Berger (ed.), Environmental restoration: Science and strategies for restoring the earth. Island Press, Washington, DC.

Heede, B. H. 1983. Control of rills and gullies in off-road vehicle traffic areas. Pages 245–264 *in* R. H. Webb and H. G. Wilshire (eds.), Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Henny, C. J., R. J. Hallock, and E. F. Hill. 1994. Cyanide and migratory birds at gold mines in Nevada, USA. *Ecotoxicology* 3:45–58.

Heske, E. J., and M. Campbell. 1991. Effects of an 11-year livestock exclosure on rodent and ant numbers in the Chihuahuan desert, southeastern Arizona. *Southwestern Naturalist* 36:89–93.

Hessing, M. B., and C. D. Johnson. 1982. Disturbance and revegetation of Sonoran desert vegetation in an Arizona powerline corridor. *Journal of Range Management* 35:254–258.

Hickman, J. C. (ed.). 1993. The Jepson manual: Higher plants of California. University of California Press, Berkeley, 1400 pp.

Hinckley, B. S., R. M. Iverson, and B. Hallet. 1983. Accelerated water erosion in ORV-use areas. Pages 81–96 *in* R. H. Webb and H. G. Wilshire (eds.), Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Humphrey, R. R. 1958. The desert grassland: A history of vegetational change and an analysis of causes. *Botanical Review* 24:193–252.

Humphrey, R. R. 1963. The role of fire in the desert and desert grassland areas of Arizona. Pages 45–62 *in* Proceedings, 2nd annual Tall Timbers fire ecology conference. Tall Timbers Research Station, Tallahasee, Florida.

Humphrey, R. R. 1974. Fire in the deserts and desert grassland of North America. Pages 365–400 *in* T. T. Kozlowski and C. E. Ahlgren (eds.), Fire and ecosystems. Academic Press, New York.

Humphrey, R. R. 1987. 90 years and 535 miles: vegetation changes along the Mexican border. University of New Mexico Press, Albuquerque, 448 pp.

Hunter, R. 1991. *Bromus* invasions on the Nevada Test Site: Present status of *B. rubens* and *B. tectorum* with notes on their relationship to disturbance and altitude. *Great Basin Naturalist* 51:176–182.

Hunter, R., F. B. Turner, R. G. Lindberg, and K.-B. Hunter. 1987. Effects of land clearing on bordering winter annual populations in the Mohave Desert. *Great Basin Naturalist* 47:234–238.

Jeffries, D. L., and J. M. Klopatek. 1987. Effects of grazing on the vegetation of the blackbrush association. *Journal of Range Management* 40:390–392.

Jennings, B. W. 1991. Desert tortoise carcass surveys along State Highways 58 and 395 San Bernardino Co., California. Prepared for the Bureau of Land Management, Riverside, California.

Johansen, J. R. 1993. Cryptogamic crusts of semiarid and arid lands of North America. *Journal of Phycology* 29:140–147.

Johnson, H. B., F. C. Vasek, and T. Yonkers. 1975. Productivity, diversity and stability relationships in Mojave Desert roadside vegetation. *Bulletin of the Torrey Botanical Club* 102:106–115.

Johnson, H. B., F. C. Vasek, and T. Yonkers. 1978. Residual effects of summer irrigation on Mojave Desert annuals. *Bulletin of the Southern California Academy of Science* 77:95–108.

Johnson, J. R., J. R. Beley, T. M. Ditsworth, and S. M. Butt. 1983. Secondary succession of arthropods and plants in the Arizona Sonoran desert in response to transmission line construction. *Journal of Environmental Management* 16:125–137.

Kay, B. L. 1979. Summary of revegetation attempts on the second Los Angeles aqueduct. *Mojave Revegetation Notes* 22:1–23.

Kay, B. L. 1988. Artificial and natural revegetation of the second Los Angeles aqueduct. *Mojave Revegetation Notes* 24:1–32.

Kay, B. L., and W. L. Graves. 1983. History of revegetation studies in the California deserts. Pages 315–324 *in* R. H. Webb, and H. G. Wilshire (eds.), Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Kleiner, E. F., and K. T. Harper. 1977. Soil properties in relation to cryptogamic groundcover in Canyonlands National Park. *Journal of Range Management* 30:202–205.

Kockelman, W. J. 1983. Introduction. Pages 1–11 *in* R. H. Webb and H. G. Wilshire (eds.), Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Lathrop, E. W. 1983a. Recovery of perennial vegetation in military maneuver areas. Pages 265–277 *in* R. H. Webb and H. G. Wilshire (eds.), Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Lathrop, E. W. 1983b. The effect of vehicle use on desert vegetation. Pages 154–166 *in* R. H. Webb and H. G. Wilshire (eds.), Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Lathrop, E. W., and E. F. Archbold. 1980a. Plant response to Los Angeles aqueduct construction in the Mojave Desert. *Environmental Management* 4:137–148.

Lathrop, E. W., and E. F. Archbold. 1980b. Plant responses to utility right of way construction in the Mojave Desert. *Environmental Management* 4:215–226.

Lathrop, E. W., and P. G. Rowlands. 1983. Plant ecology in deserts: an overview. Pages 113–152 *in* R. H. Webb and H. G. Wilshire (eds.), Environmental effects of off-road vehicles:

Impacts and management in arid regions. Springer-Verlag, New York.

Liddle, M. J. 1991. Recreation ecology: effects of trampling on plants and coral. *Trends in Evolution and Ecology* 6:13–17.

Liddle, M. J. 1997. Recreation ecology. Chapman and Hall, London, 639 pp.

Lightfoot, D. C., and W. G. Whitford. 1991. Productivity of creosotebush foliage and associated canopy arthropods along a desert roadside. *American Midland Naturalist* 125:310–322.

Lodhi, M. A. K. 1979. Allelopathic potential of *Salsola kali* L. and its possible role in rapid disappearance of weedy stage during revegetation. *Journal of Chemical Ecology* 5:429–437.

Lovich, J. E., and R. G. de Gouvenain. 1998. Saltcedar invasion in desert wetlands of the southwestern United States: ecological and political implications. Pages 447–467 *in* S. K. Majumdar, E. W. Miller, and F. J. Brenner (eds.), Ecology of wetlands and associated systems. Pennsylvania Academy of Science, Easton, Pennsylvania.

Mangis, D., J. Baron, and K. Stolte. 1991. Acid rain and air pollution in desert park areas. National Park Service, United States Department of the Interior, 129 pp.

Middleton, N. J. 1990. Wind erosion and dust-storm control. Pages 87–108 *in* A. S. Goudie (ed.), Techniques for desert reclamation. John Wiley & Sons, Chichester.

Minnich, R. A. 1983. Fire mosaics in southern California and northern Baja California. *Science* 219:1287–1294.

Mooney, H. A., S. P. Hamburg, and J. A. Drake. 1986. The invasions of plants and animals into California. Pages 250–272 *in* H. A. Mooney and J. A. Drake (eds.), Ecology of biological invasions of North America and Hawaii. Springer-Verlag, New York.

Nakata, J. K. 1983. Off-road vehicular destabilization of hill slopes: the major contributing factor of destructive debris flows in Ogden, Utah, 1979. Pages 343–353 *in* R. H. Webb and H. G. Wilshire (eds.), Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Nakata, J. K., H. G. Wilshire, and G. C. Barnes. 1976. Origin of Mojave Desert dust plumes photographed from space. Geology 4:644–648.

Nicholson, L. 1978. The effects of roads on desert tortoise populations. Pages 127–129 *in* M. Trotter (ed.), Proceedings of the 1978 symposium of the Desert Tortoise Council.

Nicholson, L., and K. Humphreys. 1981. Sheep grazing at the Kramer study plot, San Bernardino County, California. Pages 163–194 *in* K. A. Hashagen (ed.), Proceedings of the 1981 symposium of the Desert Tortoise Council.

Odum, E. P. 1994. Conservation of biodiversity. Page 18–25 *in* S. K. Majumdar, F. J. Brenner, J. E. Lovich, E. W. Miller, and J. F. Schalles (eds.), Biological diversity: problems and challenges. Pennsylvania Academy of Science, Easton, Pennsylvania.

Oldemeyer, J. L. 1994. Livestock grazing and the desert tortoise in the Mojave Desert. Pages 95–103 *in* R. B. Bury and D. J. Germano (eds.), Biology of North American tortoises. National Biological Survey, Washington, DC.

O'Leary, J. F., and R. A. Minnich. 1981. Postfire recovery of creosote bush scrub vegetation in the western Colorado Desert. *Madroño* 23:61–66.

Omar, S. A. S. 1991. Dynamics of range plants following 10 years of protection in arid rangelands of Kuwait. *Journal of Arid Environments* 21:99–111.

Poling, M. A. 1991. Legal milestones in range management. *Renewable Resources Journal* 9:7–10.

Prose, D. V. 1985. Persisting effects of armored military maneuvers on some soils of the Mojave Desert. *Environmental Geology and Water Sciences* 7:163–170.

Prose, D. V., and S. K. Metzger. 1985. Recovery of soils and vegetation in World War II military base camps, Mojave Desert. US Geological Survey. Open File Report 85-234, 114 pp.

Prose, D. V., S. K. Metzger, and H. G. Wilshire. 1987. Effects of substrate disturbance on secondary plant succession; Mojave Desert, California. *Journal of Applied Ecology* 24:305–313.

Pryor, S. C., and T. E. Hoffer. 1991. A case study of pollutant transport from Los Angeles to the desert south-west. *Atmospheric Environment* 26A:243–250.

Reible, D. D., J. R. Ouimette, and F. H. Shair. 1982. Atmospheric transport of visibility degrading pollutants into the California Mojave Desert. *Atmospheric Environment* 16:599–613.

Rejmánek, M. and J. M. Randall. 1994. Invasive alien plants in California: 1993 summary and comparison with other areas in North America. *Madroño* 41:161–177.

Reynolds, H. G., and J. W. Bohning. 1956. Effects of burning on a desert grass-shrub range in southern Arizona. *Ecology* 37:769–777.

Rice, B., and M. Westoby. 1978. Vegetative responses of some Great Basin shrub communities protected against jack rabbits or domestic stock. *Journal of Range Management* 31:28–34.

Romney, E. M., R. B. Hunter, and Wallace, A. 1990. Field trip report: natural and managed recovery of vegetation on disturbed areas at the Nevada Test Site. Pages 344–349 *in* E. D. McArthur and others (eds.), Proceedings, symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. US Forest Service, Intermountain Research Station, Ogden, Utah.

Rosen, P. C., and C. H. Lowe. 1994. Highway mortality of snakes in the Sonoran desert of southern Arizona. *Biological Conservation* 68:143–148.

Roundy, B. A., and G. L. Jordan. 1988. Vegetation changes in relation to livestock exclusion and rootplowing in southeastern Arizona. *Southwestern Naturalist* 33:425–436.

Ruch, J. B. 1968. The California Desert. California State Office BLM and Western Regional Office National Park Service, Sacramento, California, 377 pp.

Rundel, P. W., and A. C. Gibson. 1996. Ecological communities and processes in the Mojave Desert ecosystem: Rock Valley, Nevada. Cambridge University Press, Cambridge, UK 369 pp.

Savory, A. 1988. Holistic resource management. Island Press, Washington, DC, 564 pp.

Schlesinger, W. H., P. J. Fonteyn, and W. A. Reiner. 1989. Effects of overland flow on plant water relations, erosion, and soil water percolation on a Mojave Desert landscape. *Soil Science Society of America Journal* 53:1567–1572.

Schlesinger, W. H., J. F. Reynolds, G. L. Cunningham, L. F. Huenneke, W. M. Jarrell, R. A. Virginia, and W. G. Whitford.

1990. Biological feedbacks in global desertification. *Science* 247:1043–1048.

St. John, T. V. 1984. Mycorrhizal fungi and revegetation. Pages 87–93 *in* J. P. Reiger and B. A. Steele (eds.), Proceedings of the native plant revegetation symposium. Southern California Chapter and San Diego Chapter of the California Native Plant Society.

Stolte, K. W. 1991. Sensitivity of plant ecosystems in desert areas to gaseous pollutants. Pages 42–51 *in* D. Mangis, J. Baron, and K. Stolte (eds.), Acid rain and air pollution in desert park areas. National Park Service, United States Department of the Interior.

Taylor-George, S., F. Palmer, J. T. Staley, D. J. Borns, B. Curtiss, and J. B. Adams. 1983. Fungi and bacteria involved in desert varnish formation. *Microbial Ecology* 9:227–245.

Thompson, C. R. 1995. Air pollution effects on desert plants. Pages 481–488 *in* J. Latting, and P. G. Rowlands (eds.), The California desert: An introduction to natural resources and man's impact, Vol. II. June Latting Books, Riverside, California.

Thompson, C. R., G. Kats, and R. W. Lennox. 1980. Effects of SO_2 and/or NO_2 on native plants of the Mojave Desert and eastern Mojave-Colorado Desert. *Journal of the Air Pollution Control Association* 30:1304–1309.

Thompson, C. R., G. K. Olszyk, A. Bytnerowicz, P. J. Dawson, and J. Wolf. 1984a. Air pollutant injury on plants of the Mojave Desert. Southern California Edison Company, Rosemead, California, 31 pp.

Thompson, C. R., D. M. Olszyk, G. Kats, A. Bytnerowicz, P. J. Dawson, and J. W. Wolf. 1984b. Effects of ozone and sulfur dioxide on annual plants of the Mojave Desert. *Journal of the Air Pollution Control Association* 34:1017–1022.

Tierra Madre Consultants. 1991. Biological assessment for Lancaster City and planning area: Relative density surveys for desert tortoises and cumulative human impact evaluations for Mohave ground squirrel habitat, Riverside, California.

Tratz, W. M., and R. J. Vogl. 1977. Postfire vegetational recovery, productivity, and herbivore utilization of a chaparral-desert ecotone. Pages 426–430 *in* H. A. Mooney and C. E. Conrad (eds.), Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems. Forest Service, US Department of Agriculture, Washington, DC.

Trijonis, J. 1979. Visibility in the Southwest: An exploration of the historical data base. *Atmospheric Environment* 13:833–843.

Turner, R. M. 1982. Mojave desertscrub. *Desert Plants* 4:157–168.

VanCuren, T. 1995. Air pollution in the California desert: A planning perspective. Pages 489–510 *in* J. Latting and P. G. Rowlands (eds.), The California desert: An introduction to natural resources and man's impact, Vol. II. June Latting Books, Riverside, California.

Vasek, F. C. 1980. Creosote bush: long-lived clones in the Mojave Desert. *American Journal of Botany* 67(2):246–255.

Vasek, F. C., and M. G. Barbour. 1977. Mojave Desert scrub vegetation. Pages 835–867 *in* M. G. Barbour and J. Major (eds.), Terrestrial vegetation of California. John Wiley & Sons, New York.

Vasek, F. C., H. B. Johnson, and D. H. Eslinger. 1975a. Effects of pipeline construction on creosote bush scrub vegetation of the Mojave Desert. *Madroño* 23(1):1–13.

Vasek, F. C., H. B. Johnson, and G. D. Brum. 1975b. Effects of power transmission lines on vegetation of the Mojave Desert. *Madroño* 23:114–131.

Vollmer, A. T., B. G. Maza, P. A. Medica, F. B. Turner, and S. A. Bamberg. 1976. The impacts of off-road vehicles on a desert ecosystem. *Environmental Management* 1:115–129.

Walsh, P. A., and T. E. Hoffer. 1991. The changing environment of a desert boomtown. *The Science of the Total Environment* 105:233–258.

Webb, R. H. 1982. Off-road motorcycle effects on a desert soil. *Environmental Conservation* 9:197–208.

Webb, R. H. 1983. Compaction of desert soils by off-road vehicles. Pages 51–79 *in* R. H. Webb and H. G. Wilshire (eds.), Environmental effects of off-road vehicles: Impacts and management in arid regions. Springer-Verlag, New York.

Webb, R. H., and E. B. Newman. 1982. Recovery of soil and vegetation in ghost-towns in the Mojave Desert, southwestern United States. *Environmental Conservation* 9:245–248.

Webb, R. H., and S. S. Stielstra. 1979. Sheep grazing effects on Mojave Desert vegetation and soils. *Environmental Management* 3:517–529.

Webb, R. H., and H. G. Wilshire. 1983. Environmental effects of off-road vehicles: Impacts and management in arid regions. Springer-Verlag, New York. 534 pp.

Webb, R. H., H. G. Wilshire, and M. A. Henry. 1983. Natural recovery of soils and vegetation following human disturbance. Pages 279–302 *in* R. H. Webb and H. G. Wilshire (eds.) Environmental effects of off-road vehicles: Impacts and management in arid regions. Springer-Verlag, New York.

Webb, R. H., J. W. Steiger, and R. M. Turner. 1987. Dynamics of Mojave Desert shrub assemblages in the Panamint Mountains, California. *Ecology* 68:478–490.

Webb, R. H., J. W. Steiger, and E. B. Newman. 1988. The response of vegetation to disturbance in Death Valley National Monument, California. *US Geological Survey Bulletin* 1793, 103 pp.

Wedin, D. A., and D. Tilman. 1996. Influence of nitrogen loading and species composition on the carbon balance of grasslands. *Science* 274:1720–1723.

Wilshire, H. G. 1983. The impact of vehicles on desert soil stabilizers. Pages 31–50 *in* R. H. Webb and H. G. Wilshire (eds.), Environmental effects of off-road vehicles: Impacts and management in arid regions. Springer-Verlag, New York.

Wilshire, H., and D. Prose. 1987. Wind energy development in California, USA. *Environmental Management* 11:13.

Wood, M. K., R. E. Eckert, Jr., W. H. Blackburn, and F. F. Peterson. 1982. Influence of crusting soil surfaces on emergence and establishment of crested wheatgrass, squirreltail, Thurber needlegrass, and fourwing saltbush. *Journal of Range Management* 35:282–287.

Young, J. A. 1991. Tumbleweed. *Scientific American* 264:82–87.

Zink, T. A., M. F. Allen, B. Heindl-Tenburen, and E. B. Allen. 1995. The effect of a disturbance corridor on an ecological reserve. *Restoration Ecology* 3:304–310.

Am. Midl. Nat. 144:92–108

Competition Between Alien Annual Grasses and Native Annual Plants in the Mojave Desert

MATTHEW L. BROOKS
Department of Biology, University of California, Riverside 92521

AND

United States Geological Survey, Western Ecological Research Center, Box Springs Field Station, 6221 Box Springs Blvd., Riverside, California 92507[1]

ABSTRACT.—Alien annual grasses in the genera *Bromus* and *Schismus* are widespread and abundant in the Mojave Desert, and negative correlations between these aliens and native annual plants suggest that competition may occur between them. Effects of competition were evaluated by thinning alien annual grass seedlings and measuring the responses of native annual plants at three sites in the central, southcentral and southwestern Mojave Desert during 2 y of contrasting plant productivity. Effects of *Bromus* and *Schismus* were evaluated separately in the microhabitat where each was most abundant, beneath the north side of creosote bushes (*Larrea tridentata*) for *Bromus* and in the open interspace between shrubs for *Schismus*. Thinning of *Bromus* and *Schismus* significantly increased density and biomass of native annuals at all three sites, only during a year of high annual plant productivity and species richness. Effects of thinning were greatest for *Amsinckia tesselata* and for a group of relatively uncommon native annuals. Thinning also significantly increased the density and biomass of the alien forb, *Erodium cicutarium*. These results show that alien annual grasses can compete with native annual plants and an alien forb in the Mojave Desert and that effects can vary among years.

INTRODUCTION

Alien plants can alter the structure of native plant communities. In the Mojave Desert, biomass of alien annual plants is negatively correlated with biomass and species richness of native annuals, even when potential covarying factors such as disturbance and soil nutrient levels are accounted for (Brooks, 1998). In particular, biomass of alien annual grasses is negatively correlated with that of native annuals. These observations suggest that alien annuals may affect the community structure of natives in this region, possibly through interspecific competition.

Two of the most widespread and abundant alien annual plant taxa in the Mojave Desert are the annual grasses *Bromus madritensis* ssp. *rubens* (hereafter called *Bromus rubens*) and *Schismus* spp. (Brooks, 1998; Kemp and Brooks, 1998; Brooks and Berry 1999). These alien grasses affect native desert annuals by promoting wildfires (Brooks, 1999a) and possibly by competing with them for limiting resources such as nitrogen (Brooks, 1998) and water (Eissenstat and Caldwell, 1988; Melgoza and Nowak, 1991). *Bromus rubens* is invasive in its Mediterranean home range and is considered a wildland weed in the Mojave Desert (Brooks, 2000a). It has been present in this region since the early 1900s, but appears to have significantly increased in dominance since the 1970s (Hunter, 1991). *Schismus* spp. (*Schismus arabicus* and *Schismus barbatus*) is not invasive in its Middle Eastern home range, but is considered a wildland weed in the Mojave Desert (Brooks, 2000b). *Schismus* spp. invaded this region during the 1940s and apparently became dominant by the 1950s (O.

[1] Telephone/FAX (559)561-6511; e-mail: matt_brooks@usgs.gov

Clarke, pers. comm.). Two other alien annual grasses, *Bromus tectorum* and *Bromus trinii,* are locally abundant but not as widespread and common as *Bromus rubens* and *Schismus* spp. (Brooks, 1998; Kemp and Brooks, 1998; Brooks and Berry 1999).

Although competition has been shown to occur among native desert annuals (Went, 1949; Klikoff, 1966; Inouye *et al.*, 1980; Kadmon and Shmida, 1990; Pantastico-Caldas and Venable, 1993; Venable *et al.*, 1993), it has rarely been demonstrated between native and alien species (Sonoran Desert: Inouye *et al.*, 1980; Pake, 1993; Mojave Desert: Hunter, 1995). Competition between *Bromus rubens* and native annual plants was evaluated in the northern Mojave Desert by experimentally reducing its dominance by thinning and by applying a grass specific herbicide (Hunter, 1995). Although these treatments increased the average density, biomass and species richness of native annual plants, the results were not statistically significant, possibly because of insufficient sample sizes. Competition between *Schismus* and native annuals was reported in the Sonoran Desert where fecundity of *Schismus barbatus* was compared with fecundity of the native annuals *Plantago patagonica* and *Pectocarya recurvata* (Pake, 1993). At high levels of annual plant productivity, fecundity of *Schismus barbatus* was significantly higher than that of the native species, but results varied among productivity levels suggesting that the competitive hierarchies were variable. The competitive effects that dominant alien plants have on natives and the conditions where competition is most likely to occur need to be understood to effectively conserve and restore native plant communities.

The purpose of this study was to test the hypothesis that alien annual grasses in the genera *Bromus* and *Schismus* compete with native annual plants in the Mojave Desert. Competitive effects can be caused by a variety of mechanisms, including interference competition, exploitation competition, apparent competition and higher order interactions (Goldberg and Scheiner, 1993). The common characteristic of these mechanisms is that absolute abundances of plants are higher when and where abundances of their competitors are reduced. The net effect of all possible types of competition is documented in this study.

Competitive effects of alien annual grasses on native annual plants were evaluated by comparing plots that were thinned of alien grasses to unthinned reference plots. Effects were evaluated among three sites and between 2 y to evaluate spatial and temporal variation in competition. The competitive effects of *Bromus* and *Schismus* were evaluated in separate experiments because effects of aliens often vary among taxa (Lodge, 1993).

METHODS

Study sites.—Three individual 1 ha study sites were established in the central, southcentral and southwestern Mojave Desert (Rowlands *et al.*, 1982). The site within each region was located at least 25 m from dirt roads, 1 km from paved roads, 2 km from human habitations, on undeveloped land managed by the United States Department of the Interior, Bureau of Land Management. All sites had granitic soils from the early to middle Holocene which are typical of these regions of the Mojave Desert. Soils at the southwestern site were well drained, gravely, Randsburg sandy loams less than 30 cm deep over a granitic pediment (Valverde and Hill, 1981). Soil surveys were not available for the other two sites, but soils were of similar granitic sandy loam. Longterm rainfall patterns at each site were estimated by averaging the distance-weighted, monthly precipitation averages from the three closest National Oceanic and Atmospheric Administration weather stations (U.S. National Oceanographic and Atmospheric Association, 1995). Winter rainfall amounts were recorded every two weeks from October through April during this study using a single rain gauge at the center of each site.

All sites contained creosote bush scrub plant communities (Munz, 1968) dominated by

winter annual plants. Winter annuals germinate from September through December and remain as small vegetative tufts or rosettes until March or April when they rapidly grow, reproduce and die by May (Mulroy and Rundel, 1977). There are over 100 species of winter annuals compared to approximately 15 species of summer annuals in the Mojave Desert (Rowlands *et al.*, 1982). The dominant alien plants at all three sites were the winter annual grasses *Bromus rubens* and *Schismus* spp. and the forb *Erodium cicutarium*. The native winter annual grasses *Vulpia microstachys* and *Vulpia octoflora* were present at all sites, but were uncommon. Plant nomenclature followed Hickman (1993).

The central Mojave site was located south of Black and Opal mountains near Water Valley, San Bernardino County, California (35°07′30″N, 117°07′45″W) at 800 m elevation on a south facing alluvial bajada with 0–3% slope. Long-term average winter rainfall was 79 mm. The perennial plant community was dominated by *Larrea tridentata* and *Ambrosia dumosa*, but also included *Pleuraphis rigida* and *Achnatherum hymenoides*. No livestock grazing was permitted at this site since 1994 (U.S. Fish and Wildlife Service, 1994) and off highway vehicle (OHV) use was limited to roads and a few trails since 1980 (U.S. Bureau of Land Management, 1980a, b).

The southcentral Mojave site was located at the northern edge of the Ord Mountains, San Bernardino County, California (34°41′30″N, 117°57′30″W) at 1100 m elevation on a northwest facing alluvial bajada with 0–5% slope. Longterm average winter rainfall was 78 mm. *Larrea tridentata* and *Ambrosia dumosa* dominated the perennial plant community. No livestock grazing was permitted at this site since 1994 (U.S. Fish and Wildlife Service, 1994) and OHV use was limited to roads and a few trails since 1980 (U.S. Bureau of Land Management, 1980a, b).

The southwestern Mojave site was located at the southwest tip of the Rand Mountains in the Desert Tortoise Research Natural Area, Kern County, California (35°14′30″N, 117°51′15″W) at 870 m elevation on a southwest facing alluvial bajada with 0–5% slope. Longterm average winter rainfall was 104 mm. *Larrea tridentata* and *Ambrosia dumosa* dominated the perennial plant community. This site was closed to OHV use in 1973 and livestock grazing in 1976 (U.S. Bureau of Land Management, 1980ab). Further descriptions of the southwestern Mojave site can be found in Brooks (1999b).

Thinning treatments.—Effects of competition were tested by thinning the seedlings of two dominant alien annual grass genera, *Bromus* and *Schismus*, at the beginning of the growing season and evaluating the effects of thinning on density and biomass of native annuals at the end of the growing season. The relative composition of *Bromus* seedlings that were thinned was estimated because the individual species were difficult to distinguish as seedlings. *Bromus* seedlings were composed of approximately 90% *Bromus rubens* and 10% *Bromus tectorum* and *Bromus trinii*. The relative composition of *Schismus* seedlings that were thinned could not be reliably estimated.

Bromus and *Schismus* seedlings were thinned in the microhabitat where each was most abundant (Samson, 1986; Brooks, 1998; Brooks 1999c) and therefore most likely to compete with natives. *Bromus* seedlings were thinned beneath the canopy on the north side of creosote bushes (*Larrea tridentata*) (beneath-canopy microhabitat). *Schismus* seedlings were thinned in the open space between the canopies of perennial shrubs and bunchgrasses (interspace microhabitat). Seedlings were thinned using forceps and scissors and disposed of away from the plots. All aboveground portions of living plants were removed, leaving the roots intact and the soil undisturbed. Thus, alien annual grass seedlings were not completely removed, but their overall rates of photosynthesis and consumption of nutrients were reduced compared to unthinned reference plots.

Thinning treatments began when seedlings emerged approximately two weeks after the

first and only cohort of annual plants germinated during each year. The time that the treatments began varied by two weeks among sites within each year. All treatments began in January, ended in February and consisted of an initial thinning followed by a second thinning two to three weeks later. In 1996, the average number (± 1 SE) of *Bromus* seedlings thinned per 500 cm^2 plot was 128 $\pm$ 14 and the average number of *Schismus* thinned was 29 $\pm$ 4. In 1997, the average number of *Bromus* seedlings thinned per plot was 253 $\pm$ 33 and the average number of *Schismus* thinned was 52 $\pm$ 12.

Thinning experiments of this type are commonly used to evaluate competition in situ within plant communities, but they have problems (Campbell *et al.*, 1991; Goldberg and Barton, 1992). One problem is that soil disturbance and root death of thinned plants can affect soil microbial processes and the amounts of mineral nutrients such as nitrogen (Wilson and Tilman, 1991; McLennan *et al.*, 1995). Thus, effects of thinning can be erroneously attributed to competitive release when they are actually a result of altered levels of soil nutrients. Another problem is that thinning effects can vary within years depending on the phenological stages of plant species when thinning is applied (Campbell *et al.*, 1991), and possibly among years depending on the productivity and species composition of annual plant seedlings. These potential confounding effects were evaluated in the current study by monitoring levels of nitrate and ammonium in the soil of thinned and reference plots, thinning during years when only one cohort of seedlings emerged, and documenting community biomass and species composition during each year.

Experimental and sampling design.—Experimental factors were replicated at 25 stations arranged in a 5 $\times$ 5 grid at 25 m intervals within each of the three study sites. At each station four contiguous 20 $\times$ 25 cm (500 cm^2) experimental plots were placed end-to-end on their long axes in each of two microhabitats. For the *Bromus* thinning experiment, the experimental plots were placed in the beneath-canopy microhabitat of the closest creosote bush located in a random compass direction from each station. The four plots were oriented in an arc ($\sim 30°$) corresponding to the position of the beneath-canopy microhabitat. Beneath-canopy microhabitats were only used for creosote bushes with canopy diameters of at least 150 cm so the four experimental plots would fit completely within this microhabitat. For the *Schismus* thinning experiments, the experimental plots were placed in the closest interspace microhabitat located in a random compass direction >1 m from the creosote bush used for the beneath-canopy microhabitat at each station. The four plots were placed end to end in an arc of the same shape as described above for the beneath-canopy microhabitat. Individual experimental plots were randomly assigned a single level of each experimental factor, treatment (thinning and reference) and year (1996 and 1997). Hence, two plots served as thinning and reference plots during 1996 and two others served as thinning and reference plots during 1997. The total number of treatment plots was 600 (2 years $\times$ 2 treatments $\times$ 2 species(microhabitats) $\times$ 25 stations $\times$ 3 sites).

The responses of native annual plants to the thinning treatments were evaluated by collecting annual plant samples when winter annuals reached peak biomass and before they began to senesce. Samples were collected 10–18 April 1996 and 9–17 March 1997. Live annual plants were clipped at ground level within 10 x 20 cm sampling frames, counted by species, dried to a constant mass at 60 C and weighed to determine aboveground live dry biomass. Each sampling frame was centered within the 500 cm^2 experimental plots. Samples from the 2 y were considered repeated measures, because they were collected within 1 m of each other from the same microhabitat located within each station at each site.

Soil samples were collected from a random subset of six sampling frames in each of the two microhabitats after annual plants were harvested in March 1997. Samples were 8 cm diameter by 7 cm deep and were centered within the sampling frame. Soils were immedi-

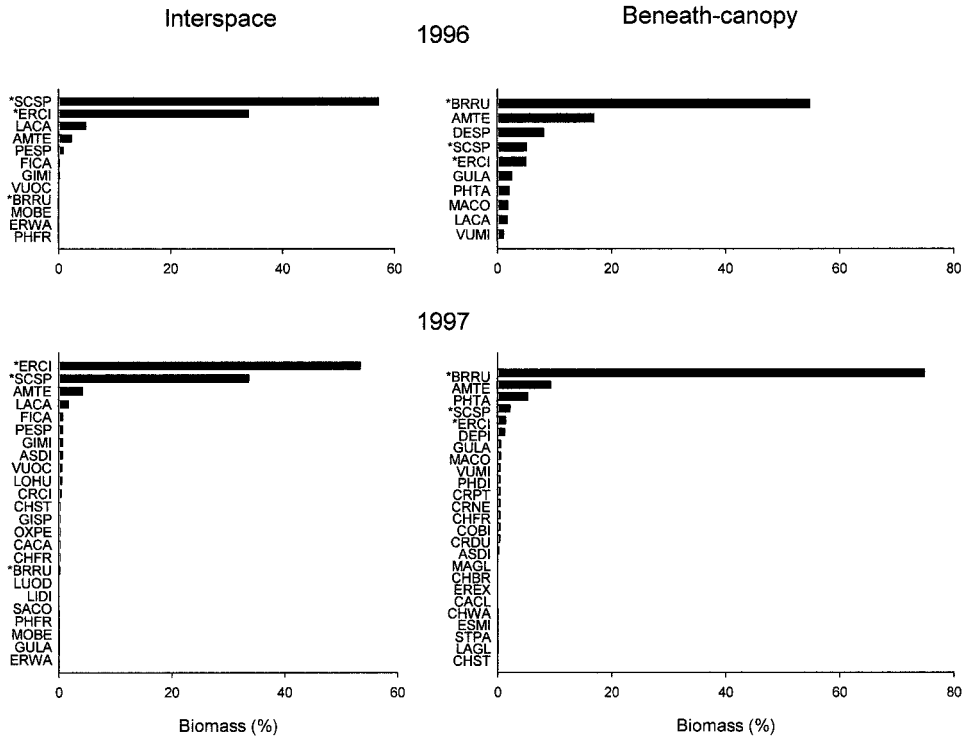

FIG. 1.—Percent biomass of annual plant species in interspace and beneath canopy microhabitats in 1996 and 1997. Species codes are defined in Appendix A; * = alien species

ately sieved (2 mm), stored in airtight plastic bags and analyzed by the University of California, Davis, Division of Agricultural and Natural Resources Analytical Laboratory.

Analysis of data.—Five dominant native annual plant taxa were evaluated individually, and the remaining less dominant native annuals were evaluated collectively as a group called "other natives" (n = 6 response variables). The dominant taxa had the highest density and biomass among natives within each microhabitat during both years at all sites, although their order of dominance varied between years (Fig. 1). The composition of the other natives group varied between microhabitats and between years. For the *Bromus* experiment, the response variables included *Amsinckia tesselata, Descurania pinnata, Malacothrix coulteri, Gullenia lasiophyllum, Phacelia tanacetifolia* and other natives. For the *Schismus* experiment, the response variables included *Amsinckia tesselata, Filago californica, Gilia minor, Lasthenia californica, Pectocarya* spp. and other natives.

Treatment effects were evaluated separately for *Bromus* thinning in the beneath-canopy microhabitat and *Schismus* thinning in the interspace microhabitat. All treatment-by-site, treatment-by-sampling station and treatment-by-site-by-sampling station interactions were not significant ($P > 0.250$), so these terms were pooled in the final model (3 sites $\times$ 25 sampling stations = 75 spatial replicates) (Underwood, 1997). The final general linear model was balanced with two fixed factors, treatment nested within year. Data were transformed using square root ($x + 0.5$) for density and species richness and $\log_{10}(x + 1)$ for

biomass (Sokal and Rohlf, 1995). These transformations made the data more normally distributed and homoscedastic.

The data were analyzed in four steps. First, graphical plots were created displaying the average density and biomass of the dominant native and alien annual plant taxa in thinning and reference treatments during 1996 and 1997. Dominant alien plants were included to evaluate the effects of thinning on the alien grass taxa that were thinned, and to evaluate potential indirect effects of thinning on natives that may have been mediated through alien taxa that were not thinned (*e.g., Erodium cicutarium*). Second, repeated measures analysis of variance (ANOVA) was used to evaluate the significance of thinning treatments on total density and biomass of all native annual plants combined during each of the two years ($\alpha \leq 0.050$). Expected mean squares and significance tests were calculated using the GLM procedure and REPEATED statement of SAS statistical software (SAS Institute, 1985). Third, multivariate analysis of variance (MANOVA) was used to evaluate the significance of thinning treatments within each year on the density and biomass of five dominant, native, annual plant taxa plus the other natives group (6 response variables). MANOVA was used instead of multiple univariate ANOVAs because it does not require equal correlations among the response variables, it reduces the chance of type I errors that can occur with multiple univariate analyses, and it allows analyses of relationships among response variables (Scheiner, 1993; von Ende, 1993). Hotelling T^2 statistic was used to evaluate multivariate differences between thinning and reference plots (Morrison 1967). Degrees of freedom for the F-value of each MANOVA were p and $(N_1 + N_2 + p - 1)$, where $p = 6$ (response variables) and $N_1 = N_2 = 75$ (replicates). Standardized canonical coefficients and graphical plots were used to evalute the relative effect of thinning treatments on each response variable. Expected mean squares, significance tests, and standardized canonical coefficients were calculated using the GLM procedure and the MANOVA statement with the CANONICAL option (SAS, 1988). This procedure produced values of Wilks' λ, from which the Hotelling T^2 statistic was calculated using the formula: $T^2 = (n - 1)(1 - \lambda/\lambda)$ (Khattree and Naik 1995). Fourth, the significance of the six response variables used in each MANOVA were evaluated individually using ANOVA and bonferroni corrected type I error rates ($P \leq 0.05/6$ tests $= 0.0083$) (Sokal and Rohlf, 1995).

RESULTS

The amount and temporal distribution of winter (Oct.–Apr.) rainfall was similar at the three study sites, but differed between years during this study. In 1995–1996, winter rainfall averaged 94% of average (82 mm) and occurred in small increments throughout the winter. In 1996–1997 rainfall averaged 77% of average (67 mm), but occurred mostly in December when rainfall was 307% of average for that month (46 mm). This high December rainfall stimulated mass germination of annual plants which resulted in high biomass and species richness of annual plants during spring 1997. In the interspace microhabitat, amounts were higher in 1997 than 1996 for average ($\pm$1 SE) annual biomass (1.05 ± 0.11 vs. 0.32 ± 0.15 g/200 cm^2) and species richness (6.78 ± 0.32 vs. 1.77 ± 0.10 species/200 cm^2). In the beneath-canopy microhabitat, amounts were also higher during 1997 than 1996 for average annual plant biomass (4.21 ± 0.40 vs. 0.12 ± 0.02 g/200 cm^2) and species richness (8.06 ± 0.35 vs. 1.79 ± 0.08 species/200 cm^2). Species composition also differed between years, with many more native species present in 1997 than 1996 (Fig. 1). Forty three species of annual plants were collected in this study (Appendix A), three of which were aliens which composed the majority of the total community biomass (Fig. 1).

Thinning treatments did not affect the amount of nitrate or ammonium present in the soil at the time annual plants were collected on 9–17 March 1997. In the beneath-canopy

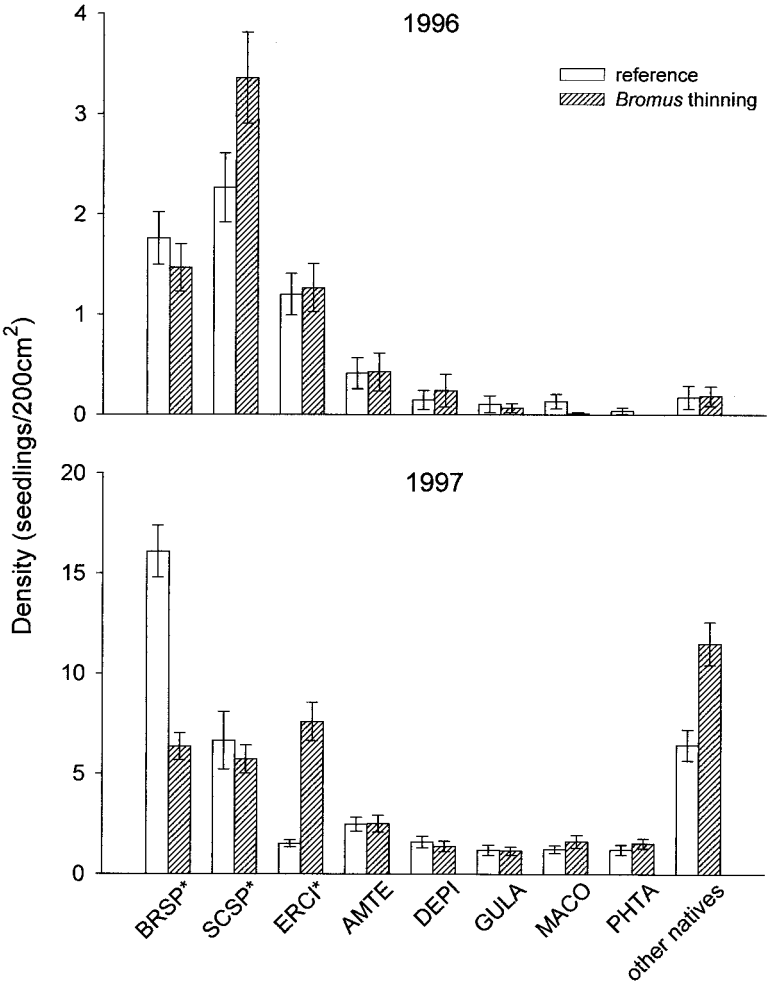

FIG. 2.—Effects of *Bromus* thinning on the density of annual plants in the beneath canopy microhabitat. Values represent the average of 25 replicates at three study sites (n = 75, +1 SE) for *Bromus rubens, Schismus* spp., *Erodium cicutarium, Descurania pinnata, Guillenia lasiophylla, Malacothrix coulteri, Phacelia tanacetifolia* and other native annuals. Species codes are defined in Appendix A; * = alien species

microhabitat, average (±1 SE) nitrate levels were 10.1 ± 1.1 ppm in treatment plots and 11.2 ± 0.9 ppm in reference plots, and ammonium levels were 3.4 ± 0.8 ppm in treatment plots and 3.7 ± 0.7 ppm in reference plots. In the interspace microhabitat, average nitrate levels were 4.8 ± 0.3 ppm in treatment plots and 4.9 ± 0.2 ppm in reference plots and ammonium levels were 1.1 ± 0.1 ppm in treatment plots and 1.0 ± 0.2 ppm in reference plots.

Effects of Bromus thinning.—Thinning reduced, but did not completely remove, density and biomass of *Bromus* in treatment compared to reference plots (Figs. 2, 3). In 1996 *Bromus* density was 17% and biomass was 4% lower in treatment than reference plots. In

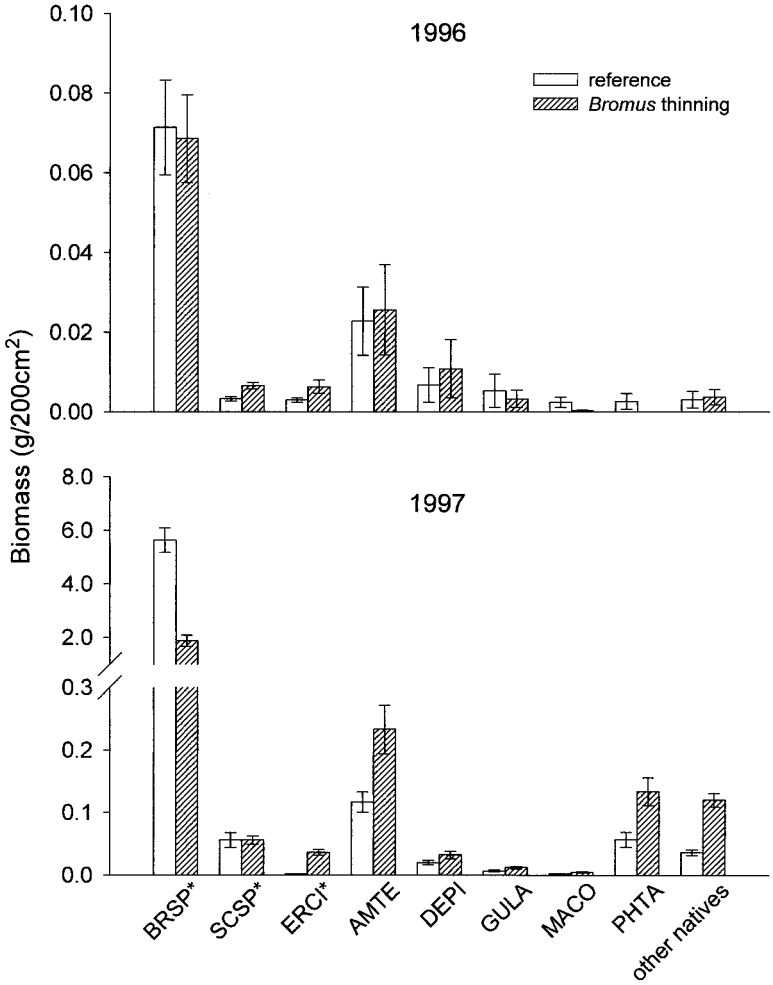

FIG. 3.—Effects of *Bromus* thinning on the biomass of annual plants in the beneath canopy microhabitat. Values represent the average of 25 replicates at three study sites (n = 75, +1 SE) for *Bromus rubens, Schismus* spp., *Erodium cicutarium, Descurania pinnata, Guillenia lasiophylla, Malacothrix coulteri, Phacelia tanacetifolia* and other native annuals. Species codes are defined in appendix A; * = alien species

1997, *Bromus* density was 61% and biomass was 67% lower in treatment than reference plots.

Thinning *Bromus* seedlings significantly affected the total density ($F_{1, 148} = 8.53$, $P = 0.004$) and biomass ($F_{1, 148} = 22.57$, $P < 0.001$) of native annual plants. Effects of thinning differed significantly between years, as indicated by significant treatment-by-year interactions for density ($F_{1, 148} = 12.25$, $P = 0.001$), and biomass ($F_{1, 148} = 35.15$, $P < 0.001$). Density and biomass of native annuals was significantly affected by thinning *Bromus* in 1997 ($F_{1, 148} = 10.89$, $P = 0.001$ and $F_{1, 148} = 32.58$, $P < 0.001$ respectively), but not in 1996 ($F_{1, 148} = 0.03$, $P = 0.865$ and $F_{1, 148} = 0.01$, $P = 0.980$ respectively). Density of natives (seedlings/

TABLE 1.—MANOVA of the effects of *Bromus* thinning in the beneath-canopy microhabitat on the density and biomass of *Amsinckia tesselata, Filago californica, Gilia minor, Lasthenia californica, Pectocarya* spp. and other native annuals

Response variable	Hotelling's T^2	F	df	P
1996				
Density	6.19	1.02	6, 143	0.412
Biomass	6.14	1.03	6, 143	0.407
1997				
Density	14.53	2.58	6, 143	0.021
Biomass	46.75	10.90	6, 143	<0.001

200 cm^2 ±1 SE) was 19.61 ± 1.43 on *Bromus*-thinned plots compared to 14.21 ± 0.88 on reference plots in 1997, and 0.93 ± 0.36 on thinned plots compared to 1.01 ± 0.29 on reference plots in 1996. Biomass of natives (g/200 cm^2) was 0.06 ± 0.02 on thinned plots compared to 0.05 ± 0.02 on reference plots in 1997, and 0.54 ± 0.06 on thinned plots compared to 0.24 ± 0.03 on references plots in 1996.

The multivariate effect of *Bromus* thinning on the six dominant native taxa was significant in 1997 but not 1996 (Table 1), although not all individual taxa were affected equally (Figs. 2, 3). For density, standardized canonical coefficients indicated that the other natives category was the group most affected by thinning treatments in 1997 (Table 2; $F_{1, 148} = 14.50$, $P < 0.001$). For biomass, other natives ($F_{1, 148} = 48.49$, $P < 0.001$) and *Amsinckia tesselata* ($F_{1, 148} = 7.63$, $P < 0.001$) were most affected by treatments.

Bromus thinning did not significantly reduce the density or biomass of *Schismus,* but did significantly reduce density and biomass of a third dominant alien, *Erodium cicutarium,* during 1997 (Figs. 2, 3). Density of *Erodium cicutarium* was significantly higher on thinned than reference plots in 1997 ($F_{1, 148} = 39.50$, $P < 0.001$) but not 1996 ($F_{1, 148} = 0.40$, $P = 0.884$), and biomass of *Erodium cicutarium* was significantly higher on thinned plots during 1997 ($F_{1, 148} = 57.11$, $P < 0.001$) but not 1996 ($F_{1, 148} = 3.76$, $P = 0.054$).

Effects of Schismus thinning.—Thinning reduced, but did not completely remove, density and biomass of *Schismus* in treatment compared to reference plots (Figs. 4, 5). In 1996, *Schismus* density was 81% and biomass was 65% lower in treatment than reference plots. In 1997, *Schismus* density was 90% and biomass was 83% lower in treatment than reference plots.

Thinning *Schismus* seedlings significantly affected the total density ($F_{1, 148} = 14.73$, $P < 0.001$) and biomass ($F_{1, 148} = 8.86$, $P = 0.003$) of native annual plants. Effects of thinning differed significantly between years, as indicated by significant treatment-by-year interactions

TABLE 2.—Standardized canonical coefficients of the first eigenvalue for the MANOVA of *Bromus* thinning in the beneath-canopy microhabitat on the density and biomass of native annual plant taxa during spring 1997. The magnitude of each coefficient corresponds to the relative effect of thinning on each response variable. Species codes are defined in appendix A

	AMTE	DEPI	GULA	MACO	PHTA	Other natives
Density	0.205	−0.202	−0.160	0.150	0.039	1.004
Biomass	0.462	0.072	0.217	0.263	0.173	0.850

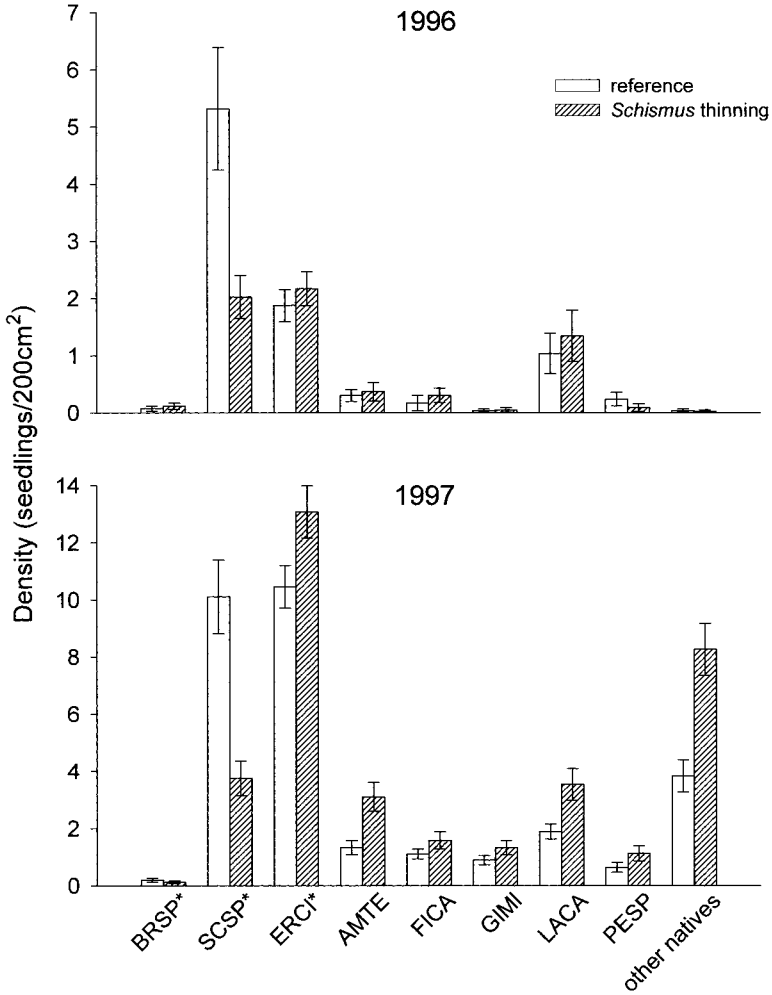

FIG. 4.—Effects of *Schismus* thinning on the density of annual plants in the beneath canopy microhabitat. Values represent the average of 25 replicates at three study sites (n = 75, +1 SE) for *Bromus rubens, Schismus* spp., *Erodium cicutarium, Amsinckia tesselata, Filago californica, Lasthenia californica, Pectocarya* spp. and other native annuals. Species codes are defined in Appendix A; * = alien species

for density ($F_{1, 148}$ = 17.41, P < 0.001), and biomass ($F_{1, 148}$ = 15.42, P < 0.001). Density and biomass of native annuals were significantly affected by thinning in 1997 ($F_{1, 148}$ = 23.24, P < 0.001 and $F_{1, 148}$ = 14.05, P < 0.001), but not in 1996 ($F_{1, 148}$ = 0.07, P = 0.793 and $F_{1, 148}$ = 0.64, P = 0.426). Density of natives (seedlings/200 cm^2) was 19.43 ± 1.40 on *Schismus*-thinned plots compared to 9.89 ± 0.75 on reference plots in 1997 and 2.12 ± 0.50 on thinned plots compared to 1.84 ± 0.40 on references plots in 1996. Biomass of natives (g/200 cm^2) was 0.18 ± 0.2 on thinned plots compared to 0.08 ± 0.01 on reference plots in 1997, and 0.03 ± 0.01 on thinned plots compared to 0.03 ± 0.01 on references plots in 1996.

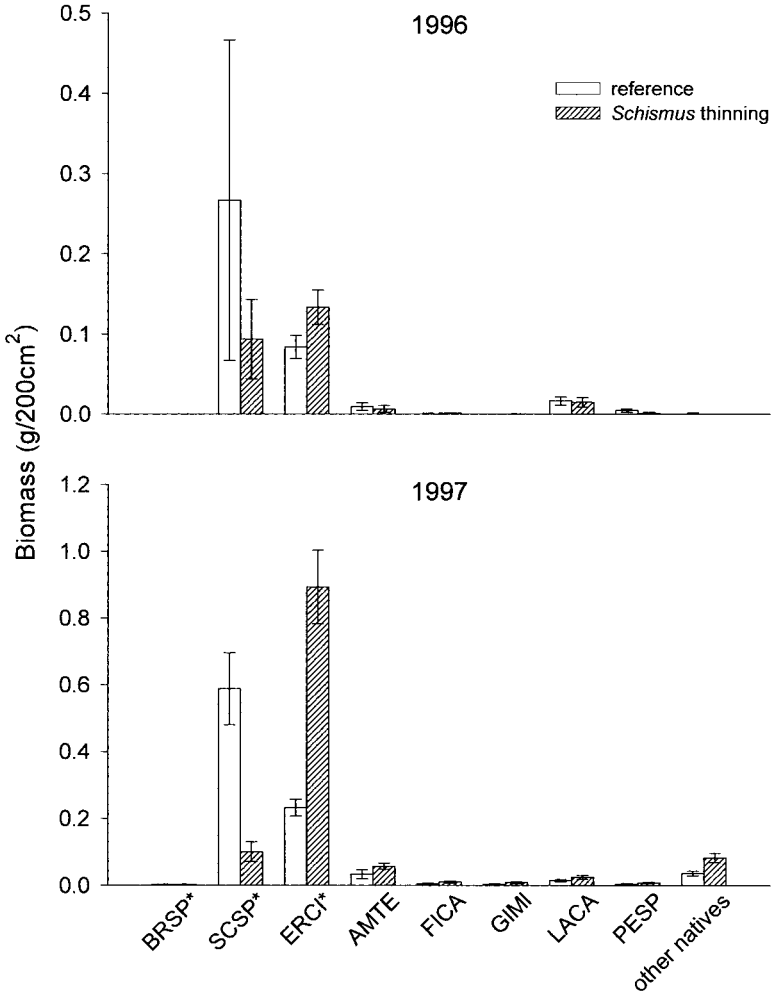

FIG. 5.—Effects of *Schismus* thinning on the biomass of annual plants in the beneath canopy microhabitat. Values represent the average of 25 replicates at three study sites (n = 75, +1 SE) for *Bromus rubens, Schismus* spp., *Erodium cicutarium, Amsinckia tesselata, Filago californica, Lasthenia californica, Pectocarya* spp. and other native annuals. Species codes are defined in Appendix A; * = alien species

The multivariate effect of *Schismus* thinning on dominant native taxa was also significant in 1997 but not 1996 (Table 3), although not all individual taxa were affected the same (Figs. 4, 5). Standardized canonical coefficients of density indicated that *Amsinckia tesselata* ($F_{1, 148}$ = 7.45, P = 0.007) and other natives ($F_{1, 148}$ = 12.63, P = 0.001) were the native taxa most affected by thinning treatments in 1997 (Table 4). Biomass of other natives was most affected by treatments in 1997 ($F_{1, 148}$ = 9.63, P = 0.002).

Schismus thinning did not significantly affect density or biomass of *Bromus* because *Bromus* was uncommon in the interspace microhabitat (Figs. 4, 5). After *Schismus* thinning, *Erodium cicutarium* significantly increased in density during 1997 ($F_{1, 148}$ = 4.98, P = 0.027)

TABLE 3.—MANOVA of the effects of *Schismus* thinning in the interspace microhabitat on the density and biomass of *Amsinckia tesselata, Descurania pinnata, Guillenia lasiophylla, Malacothrix coulteri, Phacelia tanacetifolia* and other native annuals

Response variable	Hotelling's T^2	F	df	P
1996				
Density	2.80	0.46	6, 143	0.840
Biomass	4.85	0.86	6, 143	0.570
1997				
Density	20.34	3.77	6, 143	<0.001
Biomass	14.50	2.57	6, 143	<0.001

but not 1996 ($F_{1, 148} = 0.53$, $P = 0.469$), and in biomass during 1997 ($F_{1, 148} = 39.99$, $P < 0.001$) but not 1996 ($F_{1, 148} = 3.38$, $P = 0.068$).

Other observations.—Native annual plant seedlings in reference plots began to senesce approximately 2 wk earlier than those in thinned plots during 1997. Withering shoot tissue marked the onset of senescence. Many of these senescent seedlings died before they produced seeds and were not included in the samples of live annual plants collected in March 1997. The differential senescence of annual plants between treatments was not observed in 1996.

DISCUSSION

The results of this study support the hypothesis that competition occurs between alien annual grasses and native annual plants in the Mojave Desert. Thinning of alien annual grasses increased total density and biomass of native annual plants, but significantly affected only one of the five most dominant native species. This species, *Amsinckia tesselata,* is a common forb in disturbed areas of the Mojave Desert (Hickman, 1993). The results of this study should be interpreted cautiously because it was designed to evaluate the net effects of competition. Possible indirect effects between and among alien and native species prevent definitive conclusions regarding the mechanisms of competition. Evidence is discussed below that implicates certain mechanisms that are proposed as hypotheses for further study.

Thinning treatments can produce unwanted effects that complicate the interpretation of plant competition experiments (Campbell *et al.*, 1991; Goldberg and Barton, 1992), but these confounding effects were not detected in the current study. For example, thinning treatments did not affect levels of available nitrogen in the soil, indicating that thinning did not cause changes in soil fertility. In addition, the soil was left undisturbed on thinned plots, so surface disturbance was not a factor causing differences between treatment and

TABLE 4.—Standardized canonical coefficients of the first eigenvalue for the MANOVA of *Schismus* thinning in the interspace microhabitat on the density and biomass of native annual plants during spring 1997. The magnitude of each coefficient corresponds to the relative effect of thinning on each response variable. Species codes are defined in appendix A

	AMTE	FICA	GIMI	LACA	PESP	Other natives
Density	0.619	0.058	0.256	0.280	0.129	0.612
Biomass	0.470	0.312	0.239	0.140	0.061	0.633

reference plots. Alien annual grasses can also affect natives by altering fire regimes, biogeochemical cycles and rates of leaf litter accumulation (D'Antonio and Vitousek, 1992), but these effects should not occur within the four month interval of this experiment during each year. Thus, it seems reasonable to conclude that the effects of thinning were attributable to reduced net competition from alien annual grasses.

The mechanisms by which annual plants compete with each other result in different outcomes with respect to density and biomass. Densities of annual plants can either be affected by germination inhibition or by post-germination competition for limiting resources in the deserts of southwestern North America (Went, 1949; Juhren *et al.*, 1956; Inouye, 1980; Inouye *et al.*, 1980). In contrast, biomass of annual plants is affected primarily by post-germination competition (Inouye, 1991). In the current study there was only one cohort of annual plants that germinated each year and thinning treatments were applied after these seedlings germinated, so the effects of thinning should have been caused by post-germination competition.

Accelerated senescence of native annual plants in thinned compared to reference plots suggest that alien annual grasses competed with native seedlings for water and mineral nutrients as these nutrients became less abundant at the end of the growing season. *Bromus rubens*, *Schismus* spp. and *Erodium cicutarium* can assimilate nitrogen faster than native annuals in the central, southern and western Mojave Desert (Brooks, 1998), and *Bromus tectorum* can acquire water more rapidly than native annuals in the Great Basin desert (Eissenstat and Caldwell, 1988; Melgoza and Nowak, 1991). Nitrogen and water are considered to be the two primary factors that limit plant growth in the Mojave Desert (Rundel and Gibson, 1996). Hence, the competitive superiority of some alien annuals may be linked to competition for these nutrients. Experimental manipulations of seedling densities and nutrient levels are required to test this hypothesis.

Effects of thinning were similar at all three study sites and significant only during a year of overall high productivity, suggesting that competition of aliens with natives may be widespread but varies among years. However, these hypotheses require additional testing because site and year were fixed effects in this study. Moreover, the sites were all in plant communities dominated by the widespread and common perennial shrub *Larrea tridentata*, and interactions between alien and native annuals may be different in other plant communities. In addition, the 2 yr studied differed in biomass, species richness and species composition of annual plants, all factors that may affect competitive hierarchies. Studies documenting the net effects of competition should not be generalized beyond their spatial and temporal ranges, because the multiple mechanisms that influence these net effects can vary in space and time (Goldberg and Scheiner, 1993).

Thinning treatments increased the density and biomass of *Erodium cicutarium*, a widespread and abundant alien annual forb. This species has been present in southwestern North America since the 1600s (Mensing and Byrne, 1999), in contrast to most other exotic annuals that invaded during the late 1800s and early 1900s (Heady, 1988). The increase in density and biomass of *E. cicutarium* was approximately equal to the reduction of alien annual grass abundance on thinned plots, resulting in no net change in the proportional density and biomass of aliens (Brooks, 1998). Because the density and biomass of native annual plants increased despite similar increases in *E. cicutarium*, competition between them does not appear to have been significant. However, other evidence suggests *E. cicutarium* may compete with native annuals, based on negative correlations between their abundances in the Mojave (Brooks, 1998) and Sonoran Deserts (Inouye *et al.*, 1980). Tests of the relationships between *E. cicutarium* and native annuals are required to draw any reliable conclusions about their competitive relationships.

Bromus and *Schismus* may compete with different subsets of the native annual plant community, based on their respective dominance of the beneath-canopy and interspace microhabitats and because thinning of these taxa in the microhabitat where they were each uncommon did not affect native annual plants (Brooks, 1998). Because many native annuals display preferences for one or the other of these microhabitats (Shreve, 1931; Went, 1942; Muller, 1953; Halvorson and Patten,1975; Shmida and Whittaker, 1981), *Bromus* and *Schismus* may compete with different suites of annual plant species. However, there are areas in the Mojave Desert where *Bromus* density and biomass is high across the landscape in both microhabitats (Brooks, 1998), and in these areas *Bromus* may compete with a wider range of annual plants than was observed in the current study.

The composition of annual plant communities in the Mojave Desert can vary greatly among seasons and germination cohorts (Jennings, 1993; Burk, 1982), and the results of the current study may have differed given a different suite of annual plant seedlings. This study focused on winter-germinating annual plants that grew together in a single germination cohort during each of two years. It is unknown if the effects of thinning would have been different had a second cohort of annual plants germinated after the thinning treatments were applied each year. It is also unknown if these alien winter annuals compete with native summer annuals that grow from late winter through early summer. If alien winter annuals use large amounts of soil nutrients during winter and spring, then they may affect summer annuals by reducing the amounts of nutrients available during spring and summer. This hypothesis requires testing, especially in the eastern part of the Mojave Desert where summer annuals are most abundant (Rowlands *et al.*, 1982).

This study demonstrates that alien annual grasses can significantly affect the density and biomass of native annual plant seedlings. Years of competition from these grasses may reduce the seed banks of native annuals, possibly causing fundamental changes in annual plant community structure and food web dynamics. The results also highlight the need to evaluate the effects of all dominant alien taxa, because aliens such as *Erodium cicutarium* may increase in dominance when alien annual grasses are removed. This conclusion is especially important to keep in mind when implementing management practices designed to minimize the dominance of individual species of alien annual plants.

Acknowledgments.—Funding for this study was provided by the United States Department of the Interior, Interagency Fire Coordination Committee and the United States Geological Survey, Biological Resources Division. I thank Mary Price, Kristin Berry, John Rotenberry, Richard Minnich, Edith Allen, Peter Stine and three anonymous reviewers for their helpful reviews of this manuscript.

LITERATURE CITED

BROOKS, M. L. 1998. Ecology of a biological invasion: alien annual plants in the Mojave Desert. Ph.D. Dissertation, University of California, Riverside. 186 p.

———. 1999a. Alien annual grasses and fire in the Mojave Desert. *Madroño* **46**:13–19.

———. 1999b. Effects of protective fencing on birds, lizards, and black-tailed hares in the western Mojave Desert. *Environ. Manag.*, **23**:387–400.

———. 1999c. Habitat invasibility and dominance of alien annual plants in the western Mojave Desert. *Biol. Inv.*, **1**:325–337.

———. 2000a. *Bromus madritensis* subsp. *rubens* (L.) Husnot [*B. rubens* L.], Foxtail Chess (Red Brome). *In:* C. Bossard, M. Hoshovsky and J. Randall (eds.). California deserts. Noxious wildland weeds of California. University of California Press, in press.

———. 2000b. *Schismus* spp., *Schismus arabicus* Nees and *Schismus barbatus* (L.) Thell., Mediterranean Grass (Split Grass). *In*: C. Bossard, M. Hoshovsky and J. Randall (eds.). Noxious wildland weeds of California University of California Press, in press.

——— AND K. H. BERRY. 1999. Ecology and management of alien annual plants in the CalEPPC News. California Exotic Pest Plant Council, **7**(3/4):4–6.

BURK, J. 1982. Phenology, germination, and survival of desert ephemerals in deep canyon, Riverside County, California. *Madroño,* **29**:154–163.

CAMPBELL, B. D., J. P. GRIME, J. M. L. MACKEY AND A. JALILI. 1991. The quest for a mechanistic understanding of resource competition in plant communities: the role of experiments. *Func. Ecol.,* **5**:241–253.

D'ANTONIO, C. M. AND P. M. VITOUSEK. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. *Annu. Rev. Ecol. Syst.,* **3**:63–87.

EISSENSTAT, D. M. AND M. M. CALDWELL. 1988. Competitive ability is linked to rates of water extraction. *Oecologia,* **75**:1–7.

GOLDBERG, D. E. AND A. M. BARTON. 1992. Patterns and consequences of interspecific competition in natural communities: a review of fieiled experiments with plants. *Am. Nat.,* **139**:771–801.

——— AND S. M SCHEINER. 1993. ANOVA and ANCOVA: field competition experiments, p. 69–93. *In:* S. M. Scheiner and J. Gurevitch (eds.). Design and analysis of ecological experiments. Chapman and Hall, New York.

HALVORSON, W. L. AND D. T. PATTEN. 1975. Productivity and flowering of winter ephemerals in relation to Sonoran Desert shrubs. *Am. Midl. Nat.,* **93**:311–319.

HEADY, H. F. 1988. Valley grassland, p. 491–514 *In:* M. G. Barbour and J. Major (eds.). Terrestrial vegetation of California. California Native Plant Society, Davis.

HICKMAN, J. C. (ED.). 1993. The Jepson manual: higher plants of California. University of California Press, Berkeley, California. 1400 p.

HUNTER, R. B. 1995. Status of the flora and fauna on the Nevada test site, 1994. Report DOE/NV/11432-195 for the United States Department of Energy, contract number DE-AC08-94NV11432. 363 p.

———. 1991. *Bromus* invasions on the Nevada test site: present status of *B. rubens* and *B. tectorum* with notes on their relationship to disturbance and altitude. *Gr. Bas. Nat.,* **51**:176–182.

INOUYE, R. S. 1980. Density-dependent germination response by seeds of desert annuals. *Oecologia,* **46**: 235–238.

———. 1991. Population biology of desert annual plants, p. 27–54. *In:* G. A. Polis (ed.). The ecology of desert communities. The University of Arizona Press, Tucson.

———, G. S. BYERS AND J. H. BROWN. 1980. Effects of predation and competition on survivorship, fecundity, and community structure of desert annuals. *Ecology,* **61**:1344–1351.

JENNINGS, W. 1993. Foraging ecology of the desert tortoise (*Gopherus agassizii*) in the western Mojave Desert. Master's Thesis, University of Texas at Arlington. 89 p.

JUREN, M., F. W. WENT AND E. PHILLIPS. 1956. Ecology of desert plants IV. Combined field and laboratory work on germination of annuals in the Joshua Tree National Monument, California. *Ecology,* **37**:318–330.

KADMON, R. AND A. SHMIDA. 1990. Competition in a variable environment: an experimental study in a desert annual plant population. *Isr. J. Bot.,* **39**:403–412.

KHATTREE, R. AND R. N. NAIK. 1995. Applied multivariate statistics with SAS software. SAS Institute Inc., North Carolina. 396 p.

KEMP, P. AND M. L. BROOKS. 1998. Exotic species of California deserts. *Fremontia,* **26**:30–34.

KLIKOFF, L. G. 1966. Competitive response to moisture stress of a winter annual of the Sonoran Desert. *Am. Nat.,* **75**:383–391.

LODGE, D. M. 1993. Biological invasions: lessons for ecology. *Trends in Ecol. and Evol.,* **8**:133–137.

MCLELLAN, A. J., A. H. FITTER AND R. LAW. 1995. On decaying roots, mycorrhizal colonization, and the design of removal experiments. *J. Ecol.,* **83**:225–230.

MELGOZA, G. AND R. S. NOWAK. 1991. Competition between cheatgrass and two native species after fire: implications from observations and measurements of root distribution. *J. Range. Manag.,* **44**: 27–33.

MENSING, S. AND R. BYRNE. 1999. Invasion of Mediterranean weeds into California before 1769. *Fremontia,* **27**:6–9.

MORRISON, D. F. 1967. Multivariate statistical methods. McGraw-Hill Book Company, New York. 338 p.

MULLER, C. H. 1953. The association of desert annuals with shrubs. *Am. J. Bot.*, **40**:53–60.

MULROY, T. W. AND P. W. RUNDEL. 1977. Adaptations to desert environments. *BioScience*, **27**:109–114.

MUNZ, P. A. 1968. A California flora. University of California Press, California. 1681 p.

PAKE, C. E. 1993. Sonoran Desert annual plants: empirical tests of models of coexistence and persistence in a temporally variable environment. Ph.D. Dissertation, University of Arizona, Tucson. 185 p.

PANTASTICO-CALDAS, M. C. AND D. L. VENABLE. 1993. Competition in two species of desert annuals: neighborhood analysis along a topographic gradient. *Ecology*, **74**:2192–2203.

ROWLANDS, P. G., H. B. JOHNSON, E. RITTER AND A. ENDO. 1982. The Mojave Desert, p. 103–159 *In:* G. L. Bender (ed.). Reference handbook of North American deserts. Greenwood Press, Connecticut.

RUNDEL, P. W. AND A. C. GIBSON. 1996. Ecological communities and process in a Mojave Desert ecosystem: Rock Valley, Nevada. Cambridge University Press, Cambridge. 369 p.

SAMSON D. A. 1986. Community ecology of Mojave Desert winter annuals. Ph.D. Thesis, University of Utah. 270 p.

SAS. 1988. SAS/STAT User's Guide. SAS Institute Inc. North Carolina. 1028 p.

SCHEINER. S. M. 1993. MANOVA: multiple response variables and multispecies interactions, p. 94–112 *In:* S. M. Scheiner and J. Gurevitch (eds.). Design and analysis of ecological experiments. Chapman and Hall, New York. 445 p.

SHMIDA, A. AND R. H. WHITTAKER. 1981. Pattern and biological microsite effects in two shrub communities, southern California. *Ecology*, **62**:234–251.

SHREVE, F. 1931. Physical conditions in sun and shade. *Ecology*, **12**:96–104.

SOKAL, R. R. AND F. J. ROHLF. 1995. Biometry, 3rd ed. W.H. Freeman and Company, New York. 887 p.

UNDERWOOD, A. J. 1997. Experiments in ecology: the logical design and interpretation using analysis of variance. Cambridge University Press, Cambridge. 504 p.

U.S. BUREAU OF LAND MANAGEMENT. 1980a. The California desert conservation area plan, final environmental impact statement and proposed plan, Vol. C. United States Bureau of Land Management, California Desert District, Riverside, California. 369 p.

———. 1980b. The California desert conservation area plan, final environmental impact statement and proposed plan, Vol. F. United States Bureau of Land Management, California Desert District, Riverside, California. 120 p.

U.S. FISH AND WILDLIFE SERVICE. 1994. Desert tortoise (Mojave Population) recovery plan. United States Fish and Wildlife Service, Portland, Oregon. 73 p. and appendices A through I.

U.S. NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ASSOCIATION. 1995. Climatological data annual summary, National Oceanographic and Atmospheric Association:100.

VALVERDE M. A. AND H. L. HILL 1981. Soil survey of Kern County, California, Southeastern Part. U.S. Department of Agriculture, Soil Conservation Service. 195 p.

VENABLE, D. L., C. E. PAKE AND A. C. CAPRIO. 1993. Diversity and coexistence of Sonoran Desert winter annuals. *Plan. Sp. Biol.*, **8**:207–216.

VON ENDE, C. N. 1993. Repeated-measures analysis: growth and other time-dependent measures, p. 113–137 *In:* S. M. Scheiner and J. Gurevitch (eds.). Design and analysis of ecological experiments. Chapman and Hall, New York. 445 p.

WENT, F. W. 1942. The dependence of certain annual plants on shrubs in a Southern California desert. *Bull. Torr. Bot. Club*, **69**:100–114.

———. 1949. Ecology of desert plants. II. The effect of rain and temperature on germination and growth. *Ecology*, **30**:1–13.

WILSON, S. D. AND D. TILMAN. 1991. Components of plant competition along and experimental gradient of nitrogen availability. *Ecology*, **72**:1050–1065.

SUBMITTED 5 APRIL 1998 ACCEPTED 17 JANUARY 2000

APPENDIX A.—Annual plants collected April 1996 and March 1997 at the DTNA

Amsinckia tesselata	AMTS	NF[1]	*Gilia minor*	GIMI	NF
Astragalus didymocarpus	ASDI	NF	*Gilia* species	GISP	NF
Bromus rubens	BRRU	AG	*Guillenia lasiophylla*	GULA	NF
Bromus species	BRSP	AG	*Lasthenia californica*	LACA	NF
Bromus tectorum	BRTE	AG	*Layia glandulosa*	LAGL	NF
Bromus trinii	BRTR	AG	*Linanthus dichotomus*	LIDI	NF
Camissonia campestris	CACA	NF	*Lotus humistratus*	LOHU	NF
Camissonia claviformis	CACL	NF	*Lupinus odoratus*	LUOD	NF
Chenactis fremontii	CHFR	NF	*Malacothrix coulteri*	MACO	NF
Chenactis steviodes	CHST	NF	*Malacothrix glabrata*	MAGL	NF
Chorizanthe brevicornu	CHBR	NF	*Monoptillon belliforme*	MOBE	NF
Chorizanthe watsonii	CHWA	NF	*Oxytheca perfoliata*	OXPE	NF
Coreopsis bigelovii	COBI	NF	*Pectocarya* species	PESP	NF
Crypthantha circumcissa	CRCI	NF	*Phacelia distans*	PHDI	NF
Crypthantha dumetorum	CRDU	NF	*Phacelia fremontii*	PHFR	NF
Crypthantha nevadensis	CRNE	NF	*Phacelia tanacetifolia*	PHTA	NF
Crypthantha pterocarya	CRPT	NF	*Salvia columbariae*	SACO	NF
Descurainia pinnata	DEPI	NF	*Schismus* species	SCSP	AG
Eremalche exilis	EREX	NF	*Schismus arabicus*	SCAR	AG
Eriophyllum wallacei	ERWA	NF	*Schismus barbatus*	SCBA	AG
Erodium cicutarium	ERCI	AF	*Stephanomeria parryi*	STPA	NF
Escholtzia minutiflora	ESMI	NF	*Vulpia microstachys*	VUMI	NG
Filago californica	FICA	NF	*Vulpia octoflora*	VUOC	NG

[1] AF = alien forb, AG = alien grass, NF = native forb, NG = native grass

FIRE EFFECTS ON SEED BANKS AND VEGETATION IN THE EASTERN MOJAVE DESERT: IMPLICATIONS FOR POST-FIRE MANAGEMENT

Matthew L. Brooks
Julie V. Draper
U.S. Geological Survey
Western Ecological Research Center
Las Vegas Field Station
Henderson, NV USA

INTRODUCTION

Limited information is currently available on the short-term effects of fire on soil seed banks and vegetation in the Mojave Desert. This information is critical for determining if postfire seedings are potentially beneficial, or even necessary, in this ecosystem. Of all the management tools, aerial seeding is potentially the most cost-effective over large areas because it requires the least amount of lead time. There are clearly many questions associated with this technology, but the more immediate question is whether seeding treatments are necessary in the first place. This question hinges on understanding the short-term effects of fire on the abundance and species composition of soil seed banks and germinated plants immediately following the 70,736 acre Hackberry Fire Complex which occurred at the Mojave National Preserve in the eastern Mojave Desert during late June 2005. Support for this project was provided by the Joint Fire Science Program (project #06-1-2-02).

METHODS

Six sites in the Hackberry Fire Complex were used as replicate sampling blocks, each containing one burned and one unburned experimental unit with 5 non-overlapping sampling units randomly established inside each. This randomized blocks study design consists of 6 blocks X 2 fire treatments X 5 sampling units = 60 total sampling plots. Sampling plots were set up in October 2005 and consisted of a 5 x 30m FMH brush belt transect (USDI National Park Service 2003), overlaid with a 20 x 50m modified Whittaker plot (Stohlgren et al. 1995). Burn severity measurements were collected on the brush belt transects, following FMH protocols (USDI National Park Service 2003). Four 6cm diameter x 3cm deep (volume = 85cm^3) soil samples were collected at each corner of the brush belt transect for determination of seed bank density and species richness and composited into a single soil sample. A ½ cup (111cm^3) portion was grown in a greenhouse during winter 2005-06 following methods adapted from Brenchley and Warington (1939) and modified by Young and Evans (1975). Seed bank density and species richness were measured by counting the number of germinated seedlings for each species.

Above-ground density, cover, and species richness of herbaceous and woody plants were measured during the phenological peak for annual plants in April and early May, 2006, following National Park Service FMH protocols (USDI National Park Service 2003). Spatially nested modified-Whittaker plots were used to measure plant species richness at 1, 10, 100, and 1,000m^2 scales. We focus specifically on the results of the seed bank and herbaceous plant sampling.

Data was analyzed as a randomized blocks analysis of variance (ANOVA) statistical model. The predictor variable was fire (burned, unburned). The response variables included seed bank density by groups of plants (non-native, native), above-ground vegetation density by groups, and species diversity of the seed bank and above-ground vegetation. The data was log transformed since it was not normally distributed and analyzed with SAS Proc GLIMMIX.

RESULTS AND DISCUSSION

Seed banks

Total seed bank density was significantly lower in burned (2,494 seeds/m^2) than unburned (12,460 seeds/m^2) areas ($P<0.0001$)(Fig. 1). This translates into a seed bank depletion (mortality) rate of 80%. Recent aerial seedings of postfire landscapes in the Mojave Desert have ranged from 140 seeds/m^2 (13 seeds/ft^2)(Christiana Lund, BLM, pers. comm.) to 646 seeds/m^2 (60 seeds/ft^2) (Karen Prentice, BLM, pers. comm.), and postfire drill seedings are typically applied at a rate of 323 seeds/m^2 (30 seeds/ft^2)(Karen Prentice pers. comm.). If these seeding rates were applied after the Hackberry Fire Complex, they would have only reduced the depletion rate of the seed bank to 79% if 140 seeds/m^2 were added, or 75% if 646 seeds/m^2 were added. To completely ameliorate seed bank depletion rates (to a 0% net loss), 9,966 seeds/m^2 (926 seeds/ft^2) would have to have been added, an increase of 1,543% over the highest aerial seeding rates typically used.

Non-native seed densities (dominated by *Erodium cicutarium*) were significantly lower in burned (345 seeds/m^2) than unburned (5,667 seeds/m^2) areas ($P<0.0001$)(Fig. 1) (94% depletion rate). Native seed densities were also significantly lower in burned (2,012 seeds/m^2) than unburned (6,701 seeds/m^2) areas ($P=0.0020$)(70% depletion rate). Seed bank species richness per 483cm^2 soil sample was significantly lower where burned (3 species) than unburned (6 species) ($P<0.0001$).

Above-ground herbaceous plants

Total herbaceous plant density was significantly lower in burned (107 plants/m^2) than unburned (329 plants/m^2) areas ($P<0.0001$)(Fig. 2). Non-native density was lower in burned (62 plants/m^2) than unburned (156 plants/m^2) areas ($P<0.0001$). Similarly, native density was lower where burned (45 plants/m^2) than unburned (174 plants/m^2) ($P<0.0001$). Thus, plant densities were reduced 67% during the first postfire spring, and these reductions were similar for native and non-native species. Species richness of herbaceous plants was also significantly lower in burned than unburned areas at 1m^2 (7 species vs. 10 species), 10m^2 (14 vs. 16), 100m^2 (27 vs. 30), and 1,000m^2 (40 vs. 45) spatial scales.

SUMMARY AND CONCLUSIONS

These first year results indicate that the Hackberry Fire Complex of June 2005 had the immediate effects of reducing soil seed bank and herbaceous plant density and diversity during the first postfire fall (October 2005) and spring (April-May 2006) respectively. Typical postfire seeding rates for the Mojave Desert would not have resulted in appreciable increases in seed bank densities if they had been applied after this fire, although our data do not allow us to that these differences would have not have been ecologically significant. The broader implications of these results will be better known after we evaluate results from postfire years 2 and 3.

LITERATURE CITED

Brenchley, W. E., and K. Warington. 1930. The weed seed population of arable soil. 1. Numerical estimation of viable seeds and observations on their natural dormancy. Journal of Ecology 18: 235-272.

Stohlgren, T.J., M.B. Falkner, and L.D. Schell. 1995. A Modified-Whittaker nested vegetation sampling method. Vegetatio 117:113–121.

USDI National Park Service. 2003. Fire monitoring handbook. Boise (ID): Fire Management Program Center, National Interagency Fire Center. http://www.nps.gov/fire/fire/fir_eco_monitoring.html.

Young, J. A., and R. A. Evans. 1975. Germinability of seed reserves in a big sagebrush community. Weed Science 23: 358-364.

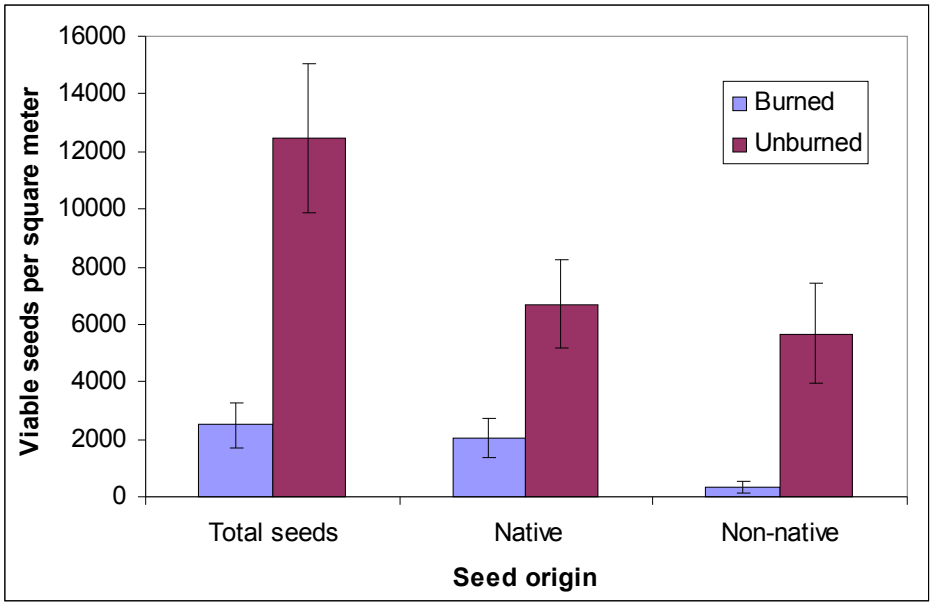

Fig. 1. Density of viable seeds in the seed bank during October 2005 following the June 2005 Hackberry Fire Complex (+/-1 SE, n=6).

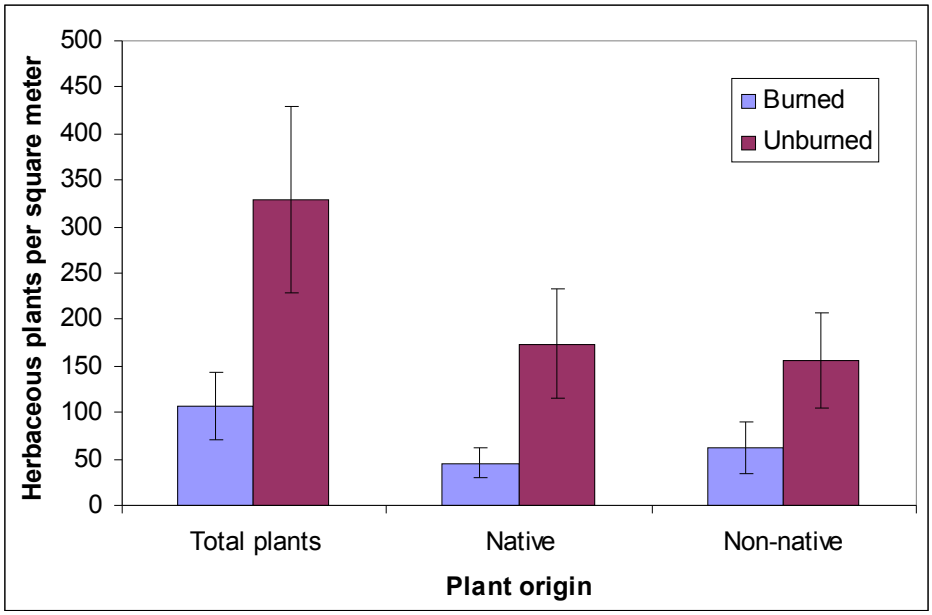

Fig. 2. Herbaceous plant density during April-May 2006 following the June 2005 Hackberry Fire Complex (+/-1SE, n=6).

Cite as: Brooks, M.L. and R.A. Minnich. *In Press*. Fire in the Southeastern Deserts Bioregion. Chp 16 in: Sugihara, N.G., J.W. van Wagtendonk, J. Fites-Kaufman, K.E. Shaffer, and A.E. Thode (eds.). Fire in California Ecosystems. University of California Press, Berkeley.

Fire in the Southeastern Deserts Bioregion

Matthew L. Brooks and Richard A. Minnich

Because of the inescapably close correlation between prevalence of fire and amount of fuel, deserts are characteristically less affected by fire than are most ecosystems … however, even though fire frequency and severity may be relatively low in any rating scale, their effect on the ecosystem may be extreme.
- Humphrey 1974, page 366.

Description of Bioregion

Physical Geography

The southeastern deserts bioregion (desert bioregion) occupies the southeastern 27% of California (110,283 km^2 or 27,251,610 acres) (Miles and Goudy 1997). The desert bioregion is within the basin and range geomorphic province of western North America, and includes two ecoregional provinces comprised of five ecological sections. The American Semi-Desert and Desert Province (hot-desert province) includes the Mojave Desert, Sonoran Desert, and Colorado Desert sections in the southern 83% of the desert bioregion (Table 16.1). The Intermountain Semi-Desert Province (cold desert province) includes the Southeastern Great Basin and Mono sections in the northern 17% of the desert bioregion.

Table 16.1. General descriptions and lightning frequencies (1985-2001) in the ecological sections of the southeastern deserts bioregion.

Ecological section[a]	% of bioregion	Constituent ecological zones[b]	Predominant Küchler vegetation types[c]	Lightning strikes/ 100km^2/yr[d]
Mojave	61	low, mid, high, montane, riparian	desert shrub 58% barren 37%	30
Sonoran	12	low, riparian	barren 82% desert shrub 18%	25
Colorado	10	low, mid, riparian	desert shrub 57% barren 38%	12
SE Great Basin	10	high montane, riparian	desert shrub 74% juniper-pinyon 18%	29
Mono	7	high, montane, riparian	sagebrush 46% juniper-Pinyon 15%	32

[a] Miles and Goudy (1997)
[b] low elevation desert shrubland, middle elevation desert shrubland and grassland, high elevation desert shrubland and woodland, desert montane woodland and forest, desert riparian woodland and oasis (see detailed descriptions in the text)
[c] potential natural vegetation types (Küchler 1964) that constitute 15% or more of the ecological section.
[d] Bureau of Land Management lightning detection data (van Wagtendonk and Cayan, in press)

The geomorphology of the desert bioregion is characterized by isolated mountain ranges with steep slopes separated by broad basins containing alluvial fans, lava flows, dunes, and playas. Elevations range from -85 m (-280 ft) below sea level in Death Valley, to 4,328 m (14,200 ft) above sea level in the White Mountains. Soil taxa range widely from hyperthermic or thermic, aridic Aridisols and Entisols in the Colorado, Sonoran, and Mojave Desert sections, to thermic, mesic, frigid, or cryic, aridic, xeric, or aquic Alfisols, Aridisols, Entisols, Inceptisols, Mollisols, and Vertisols in the Mono and Southeastern Great Basin sections (Miles and Goudy 1997). This wide range in geomorphology and soil conditions translates into a wide range of vegetation and fuel types, which include arid shrublands and semi-arid shrublands, grasslands, woodlands, and forests.

Climatic Patterns

Although frontal cyclones of the jet stream pass through the region during winter (November through April), virtually the entire desert bioregion is arid due to rain shadows of the Sierra Nevada, Transverse, and Peninsular ranges (Chapter 2, this volume). Precipitation locally increases with orographic lift in desert ranges, particularly those that rise above 2,000 m (6,096 ft). From July to early September, the region experiences 10 to 25 days of afternoon thunderstorms from the North American monsoon originating in the Gulf of California and Mexico. Thunderstorm cells tend to concentrate over high terrain, especially the eastern escarpments of the Sierra Nevada, Transverse, and Peninsular ranges, in the mountains of the eastern Mojave Desert, and in the high basin and range terrain between the White Mountains and Death Valley. The average annual precipitation on valley floors ranges from 10 to 20 cm (3.9 to 7.9 in) in the Mojave Desert and southeastern Great Basin, to 7 to 10 cm (2.8 to 3.9 in) in the Colorado and Sonoran deserts. The average annual rainfall total at Death Valley (5.8 cm, 2.3 in) is the lowest in North America. Precipitation increases to 20 to 30 cm (7.9 to 11.8 in) in the mountains above 2,000 m (6,562 ft), 40 cm (15.8 in) in the White Mountains, and 60 cm (23.6 in) in the upper leeward catchments of the Sierra Nevada, Transverse, and Peninsular ranges. The percentage of annual precipitation falling during summer (May through October) ranges from approximately 20% in the southeastern Great Basin to 40% at the Colorado River in the Sonoran Desert.

Interannual variation in rainfall is relatively high compared to other California bioregions, resulting in highly variable frequency and extent of fires among years. High rainfall produces fine fuels that promote fire spread, especially in the hot desert sections where fuels are otherwise sparse. Low rainfall causes shrub mortality which reduces woody fuel moisture and may promote fire spread in the cold desert sections where woody fuel cover is relatively high, although low fine fuel loads caused by low rainfall is probably more limiting to fire spread. Multi-decadal variation in rainfall has also been significant, with periods of relatively high rainfall from the turn of the century until 1946, a mid-century drought from 1947 to 1976, and a period of high rainfall 1977 to 1998 (Hereford et al. in press). This approximately 30-year cycle, coupled with below-average rainfall from

1999 to 2004, suggest that another 30-year drought period may be establishing, which could lead to reduced frequency and size of fires in most of the desert bioregion entering the 21st Century.

The entire desert bioregion has a large annual range of temperature due to its isolation from the stabilizing influences of the Pacific Ocean. There is also large regional variability due to variable elevational relief. Average January temperatures on valley floors range from -3 to 0° C (27 to 32° F) in the northeastern Great Basin to 7 to 10° C (45 to 50° F) in the Mojave Desert, and 11 to 13° C (52 to 55° F) in the Sonoran and Colorado deserts. Temperatures decrease with altitude to about 0° C (32° F) at 2,000 m (6,562 ft) and -8° C (18° F) at 3,000 m (9,842 ft.). During summer, average temperatures vary near the dry adiabatic lapse rate due to intense atmospheric heating in the absence of evapotranspiration under high rates of insolation. July average temperatures on valley floors range from 18 to 20° C (64 to 68° F) in the northeastern Great Basin to 25 to 30° C (77 to 86° F) in the Mojave Desert and 30 to 35° C (86 to 95° F) in the Sonoran and Colorado deserts. Maximum temperatures average > 40° C (104° F) below 1,000 m (3,281 ft) elevation and occasionally reach 50° C (122° F) in Death Valley, the Colorado River, and the Salton Sea trough. In the desert mountains, average temperatures decrease to 20° C (68° F) at 2,000 m (6,562 ft) and 10° C (50° F) at 3,000 m (9,842 ft). The decrease in temperature with altitude results in rapid decrease in evapotranspiration which in phase with increasing precipitation results in corresponding increase in woody biomass of ecosystems. Light snowpacks 10 to 15 cm (3.9 to 5.9 in) deep can develop in winter but typically disappear by spring above 2,000 m (6,562 ft), although deeper snow of 100 cm (39.4 in) can persist into the spring in subalpine forests > 3,000 m (9,842 ft).

Relative humidity during the afternoon in the summer fire season, when fires are most likely to spread, is very low throughout the desert bioregion. Average relative humidity in July ranges from 20 to 30% in the northeastern Mojave Deserts to 10 to 20% in the Mojave, Sonoran, and Colorado deserts. Values are low because moisture of the Pacific Coast marine layer is mixed aloft with dry subsiding air masses upon dissipation of the marine inversion, as well as from high temperatures produced by convective heating of surface air layers. The lowest humidity of the year (frequently < 10%) typically occurs in late June, just before the arrival of the North American monsoon.

Lightning frequency is higher in the desert than in any other California bioregion (van Wagtendonk and Cayan in press). Lightning strikes/100km^2/year averaged 27 (sd = 16) from 1985 through 2000, ranging from 32 in the Mono to 12 in the Colorado Desert sections (Table 16.1). The bioregions with the next most frequent lightning strikes were the Northeast Plateau (22 strikes/100km^2/year) and Sierra Nevada (20 strikes/100km^2/year). Most lightning in the desert bioregion occurred from July through September (78%), resulting from summer monsoons which developed in the Colorado, Sonoran, and eastern Mojave deserts, and from summer storms that developed in the Sierra Nevada mountains and drifted into the southeastern Great Basin and Mono sections. Lightning also occurred primarily during daylight hours, with 81% between 0600 and 1800.

Ecological Zones

From a fire ecology perspective, much of the variation in the desert bioregion relates to patterns of fuel characteristics and fire regimes. Vegetation (fuels), topography, and lightning strikes per unit area vary locally with elevation, and elevational vegetation gradients are correlated positively with latitudinal gradients and ecotones with more mesic regions in the immediate rain shadow of the Sierra Nevada, Transverse, and Peninsular ranges. Accordingly, we consider elevation to be the primary determinant of fire ecology zones in the desert bioregion. The ecological zones described below are listed in order of increasing elevation, except for the riparian zone, which transcends many of the other zones.

Low elevation desert shrubland zone

This is the predominant ecological zone in the Sonoran Desert section. Major vegetation types include alkali sink vegetation and the lower elevations of creosote bush scrub (Munz and Keck 1959) and succulent scrub (Rowlands 1980). Surface fuel loads and continuity are typically low, hindering the spread of fire (Fig 16.1).

Fig.16. 1. The low elevation desert shrubland ecological zone. This photo shows a creosotebush scrub vegetation typical of the Sonoran Desert.

Middle elevation desert shrubland and grassland zone

This is the predominant ecological zone in the Mojave Desert, Colorado Desert, and Southeastern Great Basin sections, where it typically occurs as an elevational band above the low elevation zone and below the high elevation zone. It also occurs at the regional ecotone between the Mojave and Great Basin deserts. Major vegetation types include Joshua tree woodland, shadscale scrub, the upper elevations of creosote bush scrub (Munz and Keck 1959), blackbrush scrub, and desert scrub-steppe (Rowlands 1980). Surface fuel characteristics are variable, but loads and continuity can be relatively high compared to the low elevation zone, facilitating the spread of fire (Fig. 16.2).

Fig. 16.2. The middle elevation desert shrubland and grassland ecological zone. This photo shows a blackrush scrubland, which typically includes blackbrush, Mojave yucca, Joshua tree, and California juniper.

High elevation desert shrubland and woodland zone

This is the predominant ecological zone in the Mono section. It also occurs at the tops of most Mojave Desert mountains or just below desert montane forests, and along the margins of the Sierra Nevada, Transverse, and Peninsular mountain ranges where they intergrade with yellow pine forests. Major vegetation types include sagebrush scrub, pinyon-juniper woodland, and desert chaparral (Munz and Keck 1959). Surface fuel loads and continuity are high where sagebrush scrub and chaparral dominate, facilitating the spread of fire. However, surface fuels are replaced by very high loads of crown fuels in closed pinyon-juniper woodlands, where fires only occur under extreme fire weather conditions and are typically very intense (Fig. 16.3).

Fig. 16.3. The high elevation desert shrubland and woodland ecological zone. This photo shows a pinyon-juniper woodland.

Desert montane woodland and forest zone

This zone is very limited in total area, and occurs almost exclusively in the Mono and Southeast Great Basin sections. Major vegetation types include bristlecone pine forest and alpine fell-fields (Munz and Keck 1959). Surface fuels are typically sparse, separating patches of crown fuels and hindering the spread of fire (Fig. 16.4).

Fig 16.4. The desert montane woodland and forest ecological zone. This photo shows a bristlecone pine forest.

Desert riparian woodland and oasis zone.

This zone includes a diverse set of vegetation types that do not fit into any single elevational range. Vegetation types include oases and riparian woodlands, shrublands, grasslands, and marshes. Surface fuels loads and continuity can be very high, facilitating fire spread, although vertical continuity of ladder fuels and horizontal continuity of crown fuels are often insufficient to carry crown fires (Fig. 16.5).

Fig. 16.5. The desert riparian woodland and oasis ecological zone. This photo shows a riparian shrubland and woodland.

Overview of Historic Fire Occurrence

The primary factor controlling fire occurrence in the desert bioregion is fuel condition, specifically fuel continuity and fuel type. Where fuel continuity is low, as in most of the low elevation and desert montane ecological zones, fires will not typically spread beyond ignition points. Even where continuity is relatively high, fuelbeds may be comprised primarily of fuel types that do not readily burn except under the most extreme fire weather conditions. The coarse, woody fuels of pinyon-juniper woodlands in the high elevation ecological zone are a good example. Thus, variations in fuel condition are central to any attempts to evaluate past or current patterns of fire occurrence.

Prehistoric

Prehistoric fire regimes have not been quantitatively described for most of the desert regions of southwestern North America, largely because the usual tools for reconstructing fire histories, such as analyzing trees for fire scars or coring sediments in swamps or lakes for charcoal deposits, cannot be used where the requisite trees or lakes are not present. As a result, past fire regimes must be inferred indirectly from prehistoric vegetation studies or current observations and data.

Fossil packrat midden data suggest that most of the desert bioregion has been under arid to semi-arid conditions since the beginning of the Holocene (~10,000 years BP), with pinyon and juniper woodlands on upper slopes and at higher elevations, and low scrub and perennial grasslands in valleys and at lower elevations (Van Devender and Spaulding 1979, Koehler et al. 2005). Most interior basins in the desert bioregion did not support permanent lakes except those receiving runoff from the Sierra Nevada, Transverse, or Peninsular ranges. Thus, the major vegetation types that presently occur in the desert bioregion, and the ecological zones described in this chapter, were likely present in the desert bioregion throughout the Holocene, expanding and contracting relative to each other as they shifted up and down elevational gradients with periods of low and high rainfall.

The low elevation ecological zone probably contained low and discontinuous fuels, hindering fire spread and resulting in low intensity, patchy burns and long fire return intervals. Consecutive years of high rainfall would have increased fine fuel loads and continuity, and may have allowed fire to spread periodically in this ecological zone, especially were rainfall was highest along the western margins of the Mojave and Colorado deserts close to the Transverse and Peninsular mountain ranges.

The middle elevation, high elevation, and riparian zones likely had sufficient perennial plant cover to periodically carry fire in the prehistoric past without significant amounts of fine fuels. Because these fires would have been carried by relatively high cover of perennial shrubs and grasses, they were likely moderate intensity, stand replacing fires, as they typically are today.

Fuels in the desert montane zone were probably discontinuous resulting in small, patchy, and very infrequent surface or passive crown fires. Evidence of this is the presence of the long-lived (>3,000 years), but fire sensitive, bristlecone pine trees (*Pinus longaeva*).

It seems highly probable that fuel conditions and fire regimes have remained relatively constant across the desert bioregion during the Holocene, although their spatial distributions likely varied as the ecotones between vegetation formations shifted with alternating periods of low and high rainfall. Current climate conditions have generally persisted since ~1,440 years BP in the Mojave Desert (Koehler et al. 2005), supporting the supposition that relative distributions of fuel conditions and ecological zones have remained relatively constant during at least the latter part of the Holocene. It is also likely that fuel conditions and fire regimes have changed significantly since the late 1880s due to land use activities and invasions by non-native annual grasses. We discuss these changes in more detail below.

Historic

Livestock grazing can reduce perennial plant cover, especially cover of perennial grasses (Brooks et al. in press), which very likely has led to reduced landscape flammability since grazing began in the desert bioregion during the late 1880s. However, at the same time that fuels were reduced due to grazing, ignitions probably increased as fire came into use by livestock operators to convert shrublands into grasslands and increase forage production, especially in the Mono and middle to high elevations of the Southern Great Basin and Mojave sections. For example, rangelands in southern Nevada, southwestern Utah, and northwestern Arizona were extensively burned during the early 1900s to reduce shrub cover and promote the growth of perennial grasses (Brooks et al. 2003). Similar rangeland burns may have also been implemented in the southern and eastern Mojave Desert and the far western Colorado Desert, where summer rainfall occurs in sufficient amounts to support large stands of perennial grasses. However, most of the southern hot desert regions are too dry to support sufficient native fuels to carry fire, so even if ranchers tried to burn, they may have often been unsuccessful.

Analyses of historical aerial photos from 1942, 1953 to 54, 1968, 1971 to 74, 1998, and 1999 at Joshua Tree National Park indicate that there were periodic fires prior to 1942 (Minnich, 2003), during a 30-year period of relatively high rainfall that lasted until 1946 (Hereford et al. in press). However, most fires were <121 ha (300 acres) with the largest encompassing 607 ha (1,500 acres), and all occurred in the middle and high elevation ecological zones (Minnich, 2003). The spatial clustering of burns in some areas suggests that deliberate burning by humans was practiced, possibly to improve range production for livestock. During the mid-century drought, only three small fires occurred, all during the 1960s and in Joshua tree woodlands of the middle elevation ecological zone. Soon after the drought ended in 1977, fires again became more prevalent, but their size and numbers eclipsed what was observed prior to the mid-century drought. The first was a 2,428 ha (6,000 acre) fire in 1978, and the most recent was a 6,070 ha (15,000 acre) complex of fires that burned over a period of 5 days in 1999, both in the middle and high elevation ecological zones. These recent fires at Joshua Tree National Park were fueled largely by old stands of native trees, shrubs, and perennial grasses, but fire spread was additionally facilitated by stands of the non-native annual grasses red brome (*Bromus madritensis* ssp. *rubens*) and cheatgrass (*Bromus tectorum*), especially where fire passed through previously

burned areas where cover of these grasses was especially high (National Park Service, DI-1202 fire reports).

Current

Records from land management agencies provide information on recent fires that can be used to reconstruct current fire regimes across the desert bioregion. We extracted data from fire occurrence records (DI-1202 reports) archived by the United States Department of the Interior and Department of Agriculture between 1980 and 2001 to create basic summaries for each of the five ecological sections in the California desert (Fig. 16.6, Table 16.2). This 21-year database is too short to capture the full range of potential burning conditions, because it was coincident with a period of above-average rainfall from 1977 to 1998 (Hereford et al. in press). However, it represents the best data available to approximate fire regimes since 1980 in the desert bioregion of California.

Table 16.2. Recent fire history (1980-2001)[a] in the ecological sections of the southeastern deserts bioregion.

Ecological section[b]	Total fires	Total Area burned	Fire frequency (fires/1000km^2/yr)	Annual area burned (ha/1000 km^2/yr)	Fire size (ha/fire)	Human: lightning fires	% of lightning strikes that resulted in fires[c]
Mojave	3158	69110	2.1	47	22	3.6	0.6
Sonoran	175	13217	0.6	47	76	7.5	0.2
Colorado	525	21340	2.2	88	41	44.2	1.8
Mono	1630	49292	9.6	292	30	0.5	2.0
SE Great Basin	90	5460	0.4	23	61	1.0	0.1
TOTAL	5578	158419	2.3	66	28	2.0	

[a] fire records (DI-1202 reports) of the Department of the Interior and Department of Agriculture, screened for errors as recommended by Brown et al. (2002).
[b] Miles and Goudy (1997)
[c] lightning frequency (van Wagtendonk and Cayan, in press) per lightning fires.

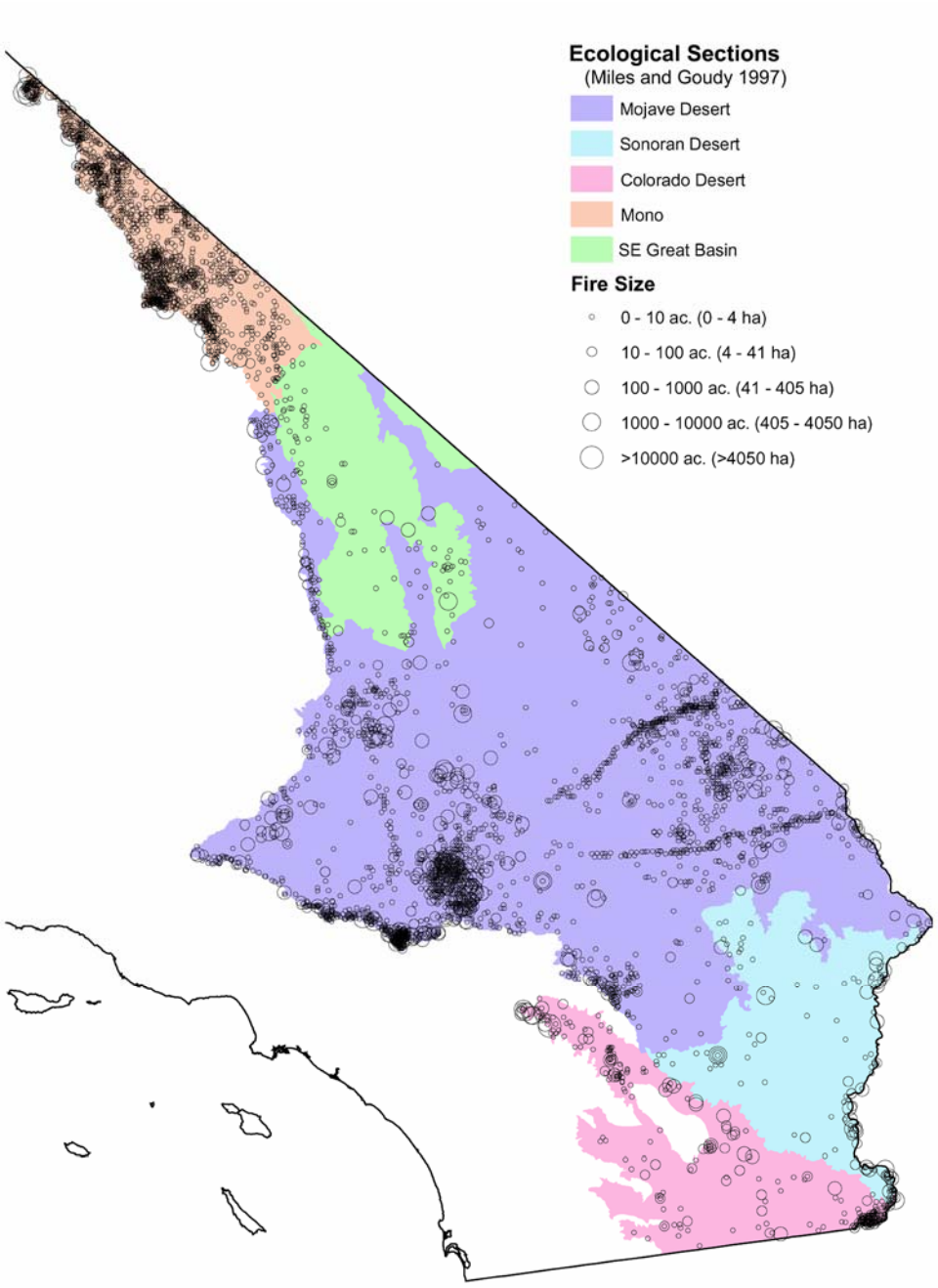

Fig. 16.6.Recent fire occurrences (1980-2001) in the five ecological sections of the Southeastern Deserts Bioregion.

The primary message from these fire records is that the proportion of total area that burned per year from 1980 to 2001 is very small, peaking in the Mono section at 0.3%/yr (292 ha/1,000 km^2/yr, Table 16.2), resulting in a fire cycle of 342 years in that ecological section. The annual fire frequency and area burned were highest in the Mono section, and lowest in the southern Great Basin section (Fig 16.6, Table 16.2), peaking from May through September. Among the hot desert regions, fire frequency was highest in the Mojave and Colorado deserts, and the annual area burned was highest in the Colorado Desert. The percentage of lightning strikes that resulted in fire was highest in the Mono and Colorado Desert sections, probably due to high fuel continuity caused by the prevalence of sagebrush steppe in the Mono section, and red brome dominated creosote bush scrub in the western Colorado section. The Colorado Desert section had the highest ratio of human:lightning caused fires. This is probably due to both the high human population density and agricultural activity in the Coachella and Imperial valleys, and the low frequency of lightning in the Colorado Desert (Table 16.1). The northern cold desert regions had the lowest frequency of fires caused by humans, probably due to its remoteness from major human population centers.

In a separate analysis of agency fire data from 1980 to 1995 in the Mojave, Colorado, and Sonoran desert sections, fires were found to be clustered in regional hotspots (Brooks and Esque 2002), where they were much more frequent and burned more proportional area than the desert-wide averages indicated in Table 16.2. Annual fire frequency increased significantly from 1980 through 1995 ($r^2 = 0.27$) (Brooks and Esque, 2002), but the increase was only significant in the low and middle elevation zones below 1,280 m (4,200 ft) ($r^2 = 0.32$, 1980 to 2001) (M. Brooks, unpublished data). A few areas burned three separate times during this 15-year interval. The increase in fire frequency was due to increased number of fires caused by humans, since the number of lightning-caused fires remained constant (Brooks and Esque, 2002). Another major contributor to increased fire frequency was a general increase in fine fuel loads caused by heightened dominance of non-native annual grasses beginning in the late 1970s (e.g. Hunter 1991) and continuing on through the 1990s (M. Brooks personal observation), probably the result of above-average rainfall from 1976 to 1998 (Hereford et al. in press). Although most fires were small and started along roadsides, most of the large fires occurred in remote areas far from major roads, and were typically started by lightning (Brooks and Esque, 2002).

Major Ecological Zones

In this section we describe the basic fire ecology of the predominant plant species in each ecological zone. We also discuss patterns of postfire succession, and interactions between plant communities, fire behavior, and fire regimes. More details on the fire ecology of a wider range of desert species can be found in other recent publications (Brown and Smith 2000, Esque and Schwalbe 2002).

Low Elevation Desert Shrubland Zone

This zone includes two primary vegetation types. Alkali sink vegetation occurs on poorly drained saline and/or alkaline playas, flats, and fans approximately -80 to 1,200 m (-63 to 3,937 ft) throughout all the ecological sections. Plant communities include iodine bush-alkali scrub, allscale-alkali scrub, Mojave saltbush-allscale scrub, and saltgrass meadow (Rowlands 1980). Creosote bush scrub vegetation occurs 0 to 1,200 m (0 to 3,937 ft) on well-drained flats, fans, and upland slopes of the Mojave, Colorado, and Sonoran Desert ecological sections. However, only the lower elevations below about 900 m (2,953 ft), were perennial plant cover is relatively low, are typical of the low elevation desert shrubland zone. Plant communities include creosote bush scrub, cheesebush scrub, succulent scrub (Rowlands 1980).

Fire responses of important species

Most shrubs in the low elevation zone do not survive after being completely consumed by fire (Humphrey 1974, Wright and Bailey 1982) (Table 16.3), but since many fires in this zone are patchy and of low intensity, plants frequently survive in unburned islands. Low fire temperatures in interspaces, and high temperatures beneath woody shrubs, likely results in relatively higher seedbank mortality for annual plants that frequent beneath-shrub than interspace microhabitats (Brooks 2002). A few perennial species that evolved to resprout after natural flooding disturbances often resprout after burning, such as desert willow (*Chiloposis linearis*), catclaw (*Acacia greggi*), smoke tree (*Dalea spinosa*), and cheesebush (*Hymenoclea salsola*) (Table 16.3). Cheesebush can have almost 100% survival rates even after being totally consumed by fire (Table 16.4). Cacti are usually only scorched during fires, as flames propagate through their spines but the stems do not ignite due to their high moisture content. Individuals with high levels of scorching typically die from uncontrolled desiccation that occurs postfire. Cactus regeneration can occur from resprouting of partially scorched plants, or rooting of fallen unburned stem fragments, but less frequently from establishment of new seedlings.

Table 16.3. Fire responses of some dominant plant species in the southeastern deserts bioregion.

Lifeform	Predominant Type of Fire Response[1]		Species
	Sprouting	Individual	
Conifer	none	killed	bristlecone pine, limber pine, pinyon pine, Utah juniper
Hardwood	fire stimulated	top-killed	shrub live oak, salt cedar*, honey mesquite, willows
	fire stimulated	underburned	Fremont cottonwood,
Shrub	fire stimulated	top-killed	catclaw acacia, smoke tree, desert willow, fourwing saltbush, cheesebush, rubber rabbitbrush, spiny hopsage, antelope bitterbrush
	none	killed	Shadscale, blackbrush, creososte bush, brittlebrush, white bursage, snakeweed, cliffrose
Stem and Leaf Succulents	none	killed	Cacti
	fire stimulated	top-killed	Mojave yucca, bananna yucca, Joshua tree[2]
Herb	fire stimulated	top-killed	bulbs
	none	killed	annual forbs
Grass	fire stimulated	top-killed	perennial grasses (e.g. Galleta grass, Indian ricegrass, desert needlegrass, fountain grass*)
	none	killed	annual grasses (e.g. red brome*, Mediterranean grass*, cheatgrass*, six-week fescue).

[1] varies depending on fire intensity and percentage of plants consumed
[2] after initially resprouting, Joshua trees often die within 5 years if most or all of their foliage was scorched or consumed
* non-native species

Table 16.4. Survival rates of perennial shrubs after being unburned (0% of living biomass burned), scorched (1-10% of living biomass burned) or consumed (11-100% of living biomass burned) during 2.25ha (5.6acre) fires in August 1995 at three low elevation shrubland sites (M. Brooks, unpublished data).

species[a]	sample size	% survival[b]			notes on fire behavior[c]
		year 1	year 4	year 8	
Central Mojave Site					
white bursage					Fire did not spread from ignition points. Therefore, the litter beneath each shrub, but not the shrub itself, was ignited. Most creosote bushes were consumed, because accumulated dead branches beneath them provided supplemental surface fuels that increased flame residency time beneath them, and ladder fuels that helped carry fire up into the creosote bush canopies.
unburned	n=20	100	100	85	
consumed	n=20	20	20	10	
creosote bush					
unburned	n=25	100	100	100	
scorched	n=4	25	25	25	
consumed	n=21	0	0	0	
Southern Mojave Site					
creosote bush					Fire spread rapidly from a few ignition points and burned 50% of the site. Few shrubs were consumed due to low fuel loads beneath creosote bushes, and low cover of finely textured sub-shrubs.
unburned	n=25	100	100	100	
scorched	n=13	77	70	62	
consumed	n=12	8	8	8	
Western Mojave Site					
white bursage					Fire spread slowly from multiple ignition points, and burned 50% of the site. Most shrubs were consumed due to high fuel loads beneath creosote bushes and the presence of many finely textured sub-shrubs.
unburned	n=10	100	100	90	
consumed	n=10	20	20	20	
cheesebush					
unburned	n=10	100	100	60	
consumed	n=10	100	100	80	
creosote bush					
unburned	n=25	100	100	100	
scorched	n=8	88	75	75	
consumed	n=17	12	12	12	
Anderson wolfberry					
unburned	n=20	100	100	90	
scorched	n=5	100	100	80	
consumed	n=20	75	75	50	

[a] Dominant perennial plant species at each site. Not all were represented by both scorched and consumed plants. white bursage = *Ambrosia dumosa*, creosote bush = *Larrea tridentata*, cheesebush = *Hymenoclea salsola*, Anderson wolfberry = *Lycium andersonii*.
[b] Shrub survival was defined as possessing live leaf tissue, either on unburned or resprouted stems, when sampled during May of 1996, 1999, and 2003.
[c] Additional descriptions of the fires and study sites are reported in Brooks 1999.

The most frequently encountered and dominant shrub in this zone, creosote bush (*Larrea tridentata*), can have 25 to 80% survival rates 8 years postfire when it is only scorched (1 to 10% biomass loss), and 0 to 12% survival rates by year 8 when it is consumed by fire (11 to 100% biomass loss) (Table 16.4). Individuals with slight to moderate scorching displayed 30 to 40% survival in the Sonoran Desert in Arizona (Dalton 1962), and in general, fire intensity and duration is inversely correlated with sprout reproduction (White 1968).

The wide range in survival rates among creosote bushes appears to be associated with their variable physiognomy and variable fuel loads beneath their canopies and across the landscape, which translate into variable fire intensity and vertical continuity from surface to canopy fuels. Individuals with canopies in the shape of inverted cones tend to occur in water-limited environments (De Soyza et al. 1997), resulting in relatively low fuel loads beneath their canopies and across the landscape and a relatively low probability of being completely consumed by fire. In contrast, individuals with hemispherical canopies that extend to the ground tend to occur in less water-limited environments (De Soyza et al. 1997), resulting in higher fuel loads beneath their canopies and across the landscape and a higher probability of being completely consumed by fire. Resprouting in creosote bushes also probably varies throughout the extensive range of this species, especially at ecotones with vegetation types that support more frequent burning. For example, moderate (O'Leary and Minnich 1981, Brown 1984) to high (Brown 1984) rates of postfire resprouting were reported at the ecotone of the western Colorado Desert with shrubland vegetation in the Peninsular ranges.

Fire regime-plant community interactions

This is the zone that Humphrey (1974) was primarily referring to when he stated that in desert shrublands "…fires are a rarity, and the few fires that do occur cause little apparent damage to the various aspects of the ecosystem…" (pp. 337). This is largely because fuels are discontinuous and characterized by a sparse 8 to 15% cover of woody shrubs, and the large interspaces between shrubs are mostly devoid of vegetation, inhibiting fire spread (Fig. 16.1). A recent summary of fire regimes of the United States (Schmidt et al. 2002) assumed that Küchler's "barren vegetation type" (Küchler 1964), which covers most of the low elevation desert shrubland zone, is mostly devoid of vegetation and therefore fireproof. However, 9% of fires and 7% of the total area burned between 1980 and 2001 occurred within the barren vegetation type in the California desert bioregion. Thus, fires do occur in the low elevation desert shrubland zone, although not as frequently and over less area than in the other zones of the desert bioregion.

Fire behavior and fire regimes in this zone are affected primarily by the ephemeral production of fine fuels from annual plants. Years of high winter and spring rainfall can increase continuity of fine fuels by stimulating the growth of annual plants that fill interspaces and allow fire to spread (Brown and Minnich 1986, Schmid and Rogers 1988, Rogers and Vint 1987, Brooks 1999). Native annuals that produce some of the most persistent fuelbeds include the annual grasses six-weeks fescue (*Vulpia octoflora*) and

small fesue (*Vulpia microstachys*), and the large forbs fiddleneck (*Amsinckia tessellata*), tansy mustard (*Descurania pinnata*), and lacy phacelia (*Phacelia tanacetifolia*), compared to a whole suite of smaller native forbs (119 species, Brooks 1999). Infrequently, successive years of high rainfall may have allowed these native annuals to build up fine fuel loads sufficient to carry fire across the interspaces between larger perennial plants. Low elevation fires carried by high loads of native annuals typically only burn dead annual plants and finely-textured sub-shrubs, leaving many of the larger woody shrubs such as creosote bush unburned. Thus, the historic fire regime was likely characterized by relatively small, patchy, low intensity surface fires, and a truncated long fire return interval (Table 16.5).

Table 16.5. Fire regime classification for desert shrubland zones.

		Vegetation Type		
		Low elevation shrubland	Middle elevation shrubland and grassland	High elevation shrubland and woodland
Desert shrubland zone	*Temporal*			
	Seasonality	Spring-summer-fall	Spring-summer- fall	Summer-early fall
	Fire Return Interval	Truncated long	Long	Long
	Spatial			
	Size	Small	Moderate to large	Moderate to Large
	Complexity	High	Multiple	Low to Moderate
	Magnitude			
	Intensity	Low	Moderate	Moderate to High
	Severity	Moderate	Moderate to high	High
	Fire Type	Surface	Passive crown to active crown	Active crown

The invasion of non-native annual grasses into the desert bioregion introduced new fuel conditions. Species such as red brome and Mediterranean grass (*Schismus arabicus* and *S. barbatus*) provide more persistent and less patchy fine fuelbeds than do native annual plants, breaking down more slowly and persisting longer into the summer and subsequent years (Brooks 1999). These new fuel conditions have the potential to increase

the size, decrease the complexity, and shorten the time interval between desert fires, although fire intensity will likely decrease because fine herbaceous non-native fuels are replacing coarse woody native fuels. These fire regime changes have occurred over a small fraction of the low elevation ecological zone, and fire regimes over the vast majority of this zone still are within the historical range of variation.

Mediterranean grass is the most widespread and abundant non-native annual grass in the low elevation shrubland zone, although red brome may predominate under large shrubs or in the less arid parts of this ecological zone. Mediterranean grass has fueled fires as large as 41 ha (100acres) (Bureau of Land Management DI-1202 records), and interspace fuel loads of as little as 112kg/ha (100 lbs/acre) are sufficient to carry fire (Brooks 1999). Because these fires burn with low intensity, soil heating is negligible and most woody shrubs are left unburned.

The recent spread of Sahara mustard (*Brassica tournefortii*) throughout the low elevation shrublands has caused concern that this invasive mustard may introduce a significant new fuel type to the desert bioregion. During years of high rainfall this invasive annual can exceed 1 m (3.3 ft) in height with a rosette of basal leaves 1 m (3.3 ft) across, and even moderately sized plants can produce as many as 16,000 seeds (M. Brooks unpublished data). Plants can remain rooted and upright through the summer fire season, and when they finally do break off they blow like a tumbleweed and lodge in shrubs or fencerows, accumulating piles of fuels similar to Russian thistle (*Salsola* spp.). There are no records of fires specifically caused by Sahara mustard in the desert bioregion, however, the combination of this species with red brome in the understory helped fuel a 20.2 ha (50 acre) fire in creosote bush scrub in northwest Arizona (M. Brooks, personal observation). During the 5 years after this fire, Sahara mustard and red brome have come to dominate this site while the native creosote bush has yet to show signs of recovery.

Non-native annual plants that evolved in other desert regions will likely be most successful at persisting in the California desert bioregion. For example, Mediterranean grass and Sahara mustard respectively evolved in the arid Middle East and Northern Africa, and they have also successfully established in the desert bioregion (Brooks 2000, Minnich and Sanders 2000). At three sites in the western Colorado Desert, these non-native species successfully persisted through two major droughts, which occurred during the end of the 1980s and 1990s (R. Minnich, unpublished data). Their cover values in 1983, 1988, and 1990 through 2001 were comparable or higher than those of the non-native forb red-stemmed filaree (*Erodium cicutarium*), which is a poorer fuel source for fires (Brooks 1999), and compared to all native forbs combined.

Middle Elevation Desert Shrubland and Grassland Zone

This zone includes five primary vegetation types. The upper elevations of creosote bush scrub that generally occur at 900 to 1,200 m (2,953 to 3,937 ft) and contain higher perennial plant cover than the lower elevations of this vegetation type. Joshua tree woodland occurs on well-drained loamy, sandy, or fine gravelly soils of mesas and gentle slopes from 760 to 1,300m (2,493 to 4,265 ft) in the Mojave Desert and Southeastern Great Basin sections. Shadscale scrub occurs on heavy, rocky, often calcareous soils with

underlying hardpan from 1,000 to 1,800m (3,281 to 5,906 ft) in the Mono, Southeastern Great Basin, and Mojave Desert sections. Blackbrush occurs on well drained, sandy to gravelly often calcareous soils from 1,000 to 2,000m (3,281 to 6,562 ft) in the southern Mono, Southeastern Great Basin and Mojave Desert sections. Desert scrub-steppe vegetation types are intermixed with a wide range of other plant communities from the low to the high elevation ecological zones, but they are most common in the middle elevation zone. Indian ricegrass scrub-steppe and desert needlegrass scrub-steppe typically occur were winter rainfall predominates within creosote bush scrub (Rowlands 1980). Big galleta scrub-steppe typically occurs in creosote bush scrub below 1,000 m (3,281 ft), and in Joshua tree woodland and blackbrush scrub above 1,000 m (3,281 ft).

Fire responses of important species

Higher fuel loads and more continuous fuelbeds in the middle elevation ecological zone result in higher intensity fires and higher frequency of top-killing in plants than in the low elevation zone. However, more species in this zone are likely to resprout after being top-killed. Perennial grasses such as desert needlegrass (*Achnatherum speciosa*), galleta grass (*Pleuraphis rigida* and *P. jamesii*), and Indian ricegrass (*Achnatherum hymenoides*) readily resprout after burning (Table 16.3). Spiny menodora (*Menodora spinescens*) and joint-fir (*Ephedra* spp.) often survive fire because their foliage does not readily burn. In contrast, some shrub species such as blackbrush (*Coloegyne ramosissima*) and winterfat (*Kraschennikovia lanata*) rarely survive burning.

Blackbrush is one of the more flammable native shrubs in the desert bioregion, due to its high proportion of fine fuels and optimal packing ratio. In the rare case that only a portion of a shrub is consumed, it may survive and resprout from the root crown. This resprouting was observed within the first few postfire years (Bates 1984), and these resprouts were still evident 20 years later (M. Brooks personal observation), at a site in the Mono section near Bishop, California. It is commonly thought that blackbrush stands take centuries to recover (Bowns 1973, Webb et al. 1988). However, analyses of historical photographs from Joshua Tree National Park and southern Nevada indicate that blackbrush stands can recover within 50 to 75 years (Minnich 2003, M. Brooks unpublished data), although other historical photographs from other locations do not indicate recovery within this time interval (M. Brooks, unpublished data). It seems probable that the ability of blackbrush to resprout after burning varies across its wide geographic range which extends from the Colorado Plateau and southern Great Basin on through the Mojave Desert.

Yucca species such as Joshua tree (*Yucca brevifolia*), Mojave yucca (*Yucca schidigera*), banana yucca (*Yucca baccata*), and Our Lord's candle (*Yucca whipplei*) are typically scorched as flames propagate through the shag of dead leaves that line their trunks. The relatively small size and more optimal packing ratio of dead Joshua tree leaves compared to dead Mojave or banana yucca leaves, increases the frequency at which they are completely burned. This may partly explain why Joshua trees are more frequently killed by fire. All four yucca species readily resprout after fire, but Joshua tree resprouts are often eaten by herbivores or otherwise die soon after burning. Postfire recruitment of new Joshua trees is infrequent, and likely occurs during years of high rainfall. No seedlings or saplings were observed in burns <10 years old, and only <10 individuals/hectare were

present on burns >40 years old in Joshua Tree National Park (Minnich 2003). Joshua tree populations along the extreme western edge of the desert bioregion often resprout and survive more readily after fire than those further east (M. Brooks personal observation). A cycle of relatively frequent fire and resprouting can result in short, dense clusters of Joshua tree clones, such as those found near Walker Pass, in the western end of the Antelope Valley, and in pinyon-juniper woodlands at ecotones with the Transverse ranges. High resprouting rates of Joshua trees in these areas may have evolved in local ecotypes that became adapted to relatively high fire frequencies at the ecotone between the desert bioregion and more mesic ecosystems to the west.

Fire regime-plant community interactions

Some of the most continuous native upland fuels in the desert bioregion occur at the upper elevations of this zone, especially in areas dominated by blackbrush (Fig. 16.2). Invasive annual grasses have contributed to increased fire frequencies since the 1970's (Brooks and Esque, 2002), although the native perennial vegetation in this zone can at times be sufficient alone to carry fire during extreme fire weather conditions (Humphrey 1974). Between 1980 and 2001, 49% of all fires and 45% of total area burned occurred in Küchler's desert shrubland vegetation type, which is roughly analogous to the middle elevation ecological zone.

At the lower elevations within this zone, where creosotebush is co-dominant with a wide range of other shrubs and perennial grasses, fire spread is largely dependent on high production of fine fuels filling interspaces during years of high rainfall (Brown and Minnich 1986, Schmid and Rogers 1988, Rogers and Vint 1987, Brooks 1999). At higher elevations within this zone, where blackbrush is often the primary dominant plant, fire spread is not so dependent on the infilling of shrub interspaces during years of high rainfall and fire occurrence does not vary as much inter-annually compared to lower elevations (M. Brooks unpublished data). Thus, the historic fire regime was likely characterized by relatively moderate to large sized, patchy to complete, moderate intensity, surface to crown fires, and a long fire return interval (Table 16.5).

The post-fire response of plant communities in blackbrush scrub is illustrative of the general responses of other desert scrub communities in the middle and high elevation ecological zones. Blackbrush fires remove cover of woody shrubs which is soon replaced by equivalent cover of herbaceous perennials and annual plants (Brooks and Matchett 2003). Alien species such as red brome, cheatgrass, and red-stemmed filaree typically increase in cover after fire, but only if rainfall is sufficient to support their growth and reproduction. Recovery of blackbrush stands may occur within 50 years (Minnich 2003, M. Brooks, unpublished data), but perhaps more typically take over 100 years (Webb et. 1988, Bowns 1973).

Red brome is the dominant invasive grass at middle elevations in the California desert bioregion. This invasive grass produces higher fuel loads and fuel depths than does Mediterranean grass, and accordingly produces longer flame lengths that carry fire into the crowns of large woody shrubs more readily, producing more intense fires (Brooks 1999). Cover of red brome can become greater and more continuous after fire, promoting recurrent fire (Sidebar 16.1, this volume). This positive invasive plant/fire regime cycle

(*sensu* Brooks et al. 2004) has shifted fire regimes outside of their historical range of variation in some regional hotspots (Brooks and Esque 2002), although fire regimes in most of the middle elevation zone are probably similar to historical conditions.

The recent invasion of the non-native annual grass African needlegrass (*Stipa capensis*) into the ecotone between the Colorado Desert and the Peninsular ranges in the 1990s has helped fuel at least one 243 ha (600 acre) fire (R. Minnich, personal observation). There are early indications that this species can survive relatively dry years, suggesting that it may spread and become another source of fine fuels that may further alter fire regimes in the desert bioregion.

High Elevation Desert Shrubland and Woodland Zone

This zone includes three primary vegetation types. Sagebrush scrub occurs in 1,100 to 2,800 m (3,600 to 9,186), although it can extend to 3,800 m (12,467 ft) in the White Mountains. Pinyon-juniper woodland occurs 1,300 to 2,400 m (4,265 to 7,874 ft), and can reach 2,700 m (8,858 ft) in the White Mountains. Both vegetation types occur in the Mono, Southeastern Great Basin, and Mojave sections. Among the pinyon-juniper vegetation types, the Utah juniper – single-leaf pinyon association is the most widespread, occurring in the Mono, Southeastern Great Basin, and eastern Mojave Desert ecological sections of California (Minnich and Everett 2001). The California juniper – single-leaf pinyon association occurs along the desert slopes of the Transverse ranges at the edge of the Mojave Desert section, with California juniper dominating below 1,700 m and single-leaf pinyon dominating above. Desert chaparral is the least prevalent of the major vegetation types in this ecological zone. It occurs on the middle slopes of the Transverse ranges adjacent to the Mojave Desert, and the Peninsular ranges adjacent to the Colorado Desert, below the mixed conifer forests, and in the same general elevation range as sagebrush scrub and pinyon-juniper woodland.

Fire responses of important species

Relatively high fuel loads result in high fire intensity, but plant mortality rates can vary widely among species. Wyoming big sagebrush (*Artemisia tridentate* ssp. *wyominensis*) is typically killed by fire, but it often re-establishes readily from wind-dispersed seeds. Cliffrose (*Purshia mexicana*) is typically killed by fire, whereas its close relative, antelope bitterbrush (*Purshia tridentata*), exhibits highly variable responses to fire, sometimes resprouting (Table 16.3). Interior chaparral species, such as *Quercus cornelius-mulleri, Q. turbinella, Cercocarpus betuloides, Arctostaphylos glauca,* and *A. glandulosa, Nolina* spp., either resprout or reseed soon after fire, but lower rainfall and sparser vegetation cover results in less frequent fire and slower recovery rates than is typical of cis-montane chaparral.

Pinyon pine (*Pinus monophylla*, *P. edulis*) and juniper (*Juniperus osteosperma*, *J. californica*) are typically killed by fire, but these woodlands can re-establish after 100+ years of fire exclusion. Juniper typically re-establishes from seed sooner than pinyon pine. Initial establishment of single-leaf pinyon pine appears to be delayed 20 to 30 years by sun

scald and/or freeze/thaw soil heaving until the establishment of the shrub layer and young juniper trees which act as nurse plants (Wangler and Minnich 1996). The first pinyon recruits establish within the canopies of nurse plants, often near root axes. The establishment of a pinyon pine canopy after about 75 years eventually reduces freeze-thaw processes, setting off a chain-reaction of spatially random recruitment throughout old burns. Pinyons develop complete canopy closure after 100 to 150 yr which is accompanied by a decline in the surface vegetation, due apparently to shrub senescence and shade stress.

Fire regime-plant community interactions

Fuel continuity is similar to that of the middle elevation zone, but the fuels are generally more woody and difficult to ignite. In addition to high plant cover, the prevalence of steep slopes in this ecological zone facilitates the spread of fire. Due to the high biomass of woody fuels created by juniper and pinyon pine, and to a lesser extent sagebrush (*Artemisia* spp.), bitterbrush, cliffrose, and scrub oak (*Quercus turbinella*), the fires that do start are among the most intense encountered in the desert bioregion. Between 1980 and 2001, 33% of fires and 45% of the total area burned occurred in Küchler's sagebrush, juniper-pinyon, and chaparral vegetation types which are characteristic of the high elevation ecological zone.

Fire spread can occur most any year in sagebrush steppe, although it is more likely when fine fuel loads (especially cheatgrass and red brome) are high following years of high rainfall, or during periods of high winds and low relative humidity. Fires are patchy to complete, moderate intensity passive crown to crown fires, depending the continuity of the woody shrub fuels. Fire spread in pinyon-juniper woodlands is most probable when live fuel moisture and relative humidity are low and winds are high. When fires did historically occur, they were mostly large, intense crown fires, burning through woodland crown fuels. At the interface between sagebrush steppe and pinyon-juniper woodland, a surface to passive crown fire regime is the norm, as fire spreads through woody and herbaceous surface fuels and occasionally torches woodland fuels, especially younger trees. The historic fire regime was likely characterized by relatively large, patchy to complete, moderate intensity surface to crown fires, and a long fire return interval (Table 16.5).

Sagebrush stands generally require 30 to 100 years to recover following fire (Whisenant 1990). Where cheatgrass has dramatically shortened fire return-intervals, especially in the lower elevation Wyoming big sagebrush communities, sagebrush steppe has been converted to non-native annual grassland (Sidebar 16.1, this volume). In the higher elevation mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) communities, this type conversion is much less common, since the native shrubs and perennial grasses recover much more rapidly after fire.

Fire suppression coupled with removal of fine fuels by livestock grazing has allowed pinyon-juniper woodlands to encroach on sagebrush steppe across much of the western United States (Miller and Tausch 2001), including the Mono section of the desert bioregion. However, it is less likely that woodland encroachment has occurred in the more arid hot desert regions, due to low primary productivity rates. Recent resampling of 1929 to 1934 California Vegetation Type Map (VTM) survey plots reveal no significant changes in woodland densities at the western edge of the hot desert regions (Wangler and Minnich

1996). Pinyon-juniper woodlands adjacent to the Transverse ranges have experienced long periods between stand-replacement fires both before and after fire suppression began (fire rotation periods, ~450 years; Wangler and Minnich 1996).

Fires in pinyon-juniper woodlands are least frequent in open stands at lower elevations and more frequent in dense forests at higher elevations, in response to changing productivity and fuel accumulation gradients with increasing elevation and rainfall. The upper elevation ecotones between pinyon-juniper woodlands and mixed conifer forest are typically very narrow, due to truncated disturbance gradients related to fire behavior and stem mortality (Minnich 1988). The thin bark of pinyon pine prevents their survival in the frequent surface fire regime typical of mixed conifer forests. Alternatively, postfire surface fuels appear to lack sufficient biomass to support short-period burns, and as canopy closure occurs in pinyon and juniper woodlands, surface fuel loads and continuity are further reduced. Thus, a historical discontinuity in fire return intervals probably existed along the ecotones between mixed conifer forests and pinyon woodlands in which understory surface fires at high elevations shift to long-period stand-replacement crown fires at lower elevations in response to differences in stand structure, fire behavior, and tree survivorship (Minnich 1988).

Desert Montane Woodland and Forest Zone

There are two primary vegetation types in this ecological zone. Bristlecone-limber pine forests occur on well-drained, shallow, dolomitic soils from 2,600 to 3,800 m (8,530 to 12,467 ft) in the Inyo, White, Panamint, Funeral, and Grapevine mountains. Alpine fell-fields occur above timberline, primarily in the White Mountains. Small white fir forest enclaves also occur on north-facing slopes from 1,900 to 2,400m (6,234 to 7,874 ft) in the New York, Clark, and Kingston mountains of the Mojave Desert section (Rowlands 1980).

Fire responses of important species

The flagship tree species of this ecological zone, bristlecone pine and limber pine (*Pinus flexilis*), have thin bark which makes them susceptible to mortality during fires (Table 16.3). Although most individuals are struck by lightning by the time they are 1,000 years old, strikes may not result in the entire tree burning, since many old individuals have scars resulting from multiple lighting strikes. The presence of ancient bristlecone pine individuals is testimony to the historical infrequency of fire. As a result, most plant species in this zone are not adapted to recovery from fire, although species associated with other periodic natural disturbances such as from colluvial erosion may be able to resprout after burning.

Fire regime-plant community interactions

Fuels are very discontinuous, but in contrast to the low elevation zone, ephemeral production by annuals during years of high rainfall adds very little to the fuel bed, due to shallow soils, low temperatures, and a short growing season. As a result, surface fires are extremely rare, and most fires that do occur spread through the crowns of pines only

during extreme fire weather conditions, but even these fires are very small <1ha (2.5 acres). Between 1980 and 2001, <1% of all fires and total area burned occurred in Küchler's great basin pine, alpine meadows-barren, and mixed conifer vegetation types characteristic of the desert montane ecological zone.

Low productivity results in very low fuel loads and continuity in the desert montane forests. Except on steep, north-facing canyons, heavy fuels are widely spaced and fine fuels are low and relatively unflammable, making it difficult to carry fire in this landscape. Thus, the historic fire regime is characterized by truncated small, patchy, variable intensity, passive crown fires, and a truncated long fire return interval (Table 16.6).

Table 16.6. Fire regime classification for the desert montane woodland, and riparian woodland/oasis zones.

Desert montane woodland, and riparian woodland/oasis zone	*Vegetation Type*		
		Desert montane woodland	Riparian woodland/oasis zone
	Temporal		
	Seasonality	Summer-early fall	Spring-summer-fall
	Fire Return Interval	Truncated long	Short to moderate
	Spatial		
	Size	Truncated small	Small to moderate
	Complexity	Moderate	Low
	Magnitude		
	Intensity	Multiple	High
	Severity	Multiple	Multiple
	Fire Type	Passive Crown	Passive to active crown

Desert Riparian Woodland and Oasis Zone

Riparian woodlands occur primarily along the Colorado and Mojave river corridors adjacent to low elevation shrublands in the southern desert region. Other examples can be found in the Amargosa Gorge, Whitewater River, Andreas Canyon, and Palm Canyon. In the northern desert region, riparian woodlands occur along the Owens and Walker rivers and the many creeks along the east slope of the Sierra Nevada Mountains. Oasis woodlands occur in isolated stands such as the Palm Canyon, Thousand Palms, and Twentynine-palms oases in the Colorado Desert section.

Fire responses of important species

Woodland dominants such as Fremont cottonwood (*Populus fremontii*) honey mesquite (*Prosopis glandulosa*), and willows (*Salix* spp.) typically resprout after being topkilled (Table 16.3). However, resprouting individuals and seedlings are susceptible to mortality during recurrent fires. Oasis species such as Washington fan palm (*Washingtonia filifera*) benefit from frequent, low-intensity fire, which reduces competition for water from other plants growing at the surface, and allow new seedlings to become established.

Fire regime-plant community interactions

Fuel characteristics and fire behavior are extremely variable, due to the wide range of vegetation types that characterize the riparian zone. In general fuels are typically continuous and fuel loads high, but fuel moisture content is also often high. Fires may not carry except under extreme fire weather conditions. Thus, the historic fire regime is characterized by small to moderate sized, complete, high intensity passive to active crown fires, and a short to moderate fire return interval (Table 16.6).

In riparian woodlands the invasives saltcedar (*Tamarix* spp), and less frequently giant reed (*Arundo donax*), create ladder fuels that allow fire to spread from surface fuels of willow (*Salix* spp.), saltbush (*Atriplex* spp.), sedge (*Carex* spp.), reed (*Juncus* spp.), and arrow weed (*Pluchea sericea*) into the crowns of overstory Fremont cottonwood trees, top-killing them. After an initial fire, these invasive quickly recover and surpass their pre-fire dominance, promoting increasingly more frequent and intense fires which, can eventually displace most native plants (Sidebar 16.2, this volume).

In palm oases, Washington fan palms depend on surface fire to clear understory species and facilitate recruitment. However, these sites can be pre-empted by saltcedar as it rapidly recovers after fire. The ladder fuels saltcedar creates can also carry fire into the crown of Washington fan palms, increasing the incidence of crown fires (Sidebar 16.2, this volume)

Management Issues

Fuels Management

The deserts of southwestern North America are one of the fastest growing regions in terms of human populations in the United States. As human populations increase, so to do the number of people living at the wildland-urban interface, which complicates fire management in many ways (Chapter 19, this volume). Increasing human populations can also potentially change fuel characteristics, through increased air pollution which can increase deposition rates of atmospheric nitrogen, and potentially increase fine fuel loads (Brooks 2003). Burgeoning human populations can also increase the introduction rates of new plant species that could add new fuel components and fire hazards to the region (Chapter 22, this volume). Since fire spread is mostly limited by the availability of contiguous fuels, fuel management can be a very important tool for fire managers in the California desert bioregion, even though the areas in which it is used may be a small percentage of the total region.

Herbaceous fuel management

The fuel component of greatest concern in the desert bioregion is the continuous cover the non-native annual grasses red brome, cheatgrass, and Mediterranean grass that appear during years of high rainfall. Although populations of these non-native annual plants and their resultant fine fuel loadings wax and wane with annual and multi-decadal fluctuations in rainfall (Sidebar 16.1, this volume), they have changed fire behavior and fire regimes in many parts of the desert bioregion, especially in the low elevation ecological zone where their presence is almost a prerequisite for large fires.

Despite all the concern surrounding the non-native species already dominating the desert bioregion, new grass invaders such as fountain grass (*Pennisetum setaceum*), buffelgrass (*Cenchrus ciliare*), and African needlegrass, and invasive mustards such as Sahara mustard, may pose additional fire hazards in the future. For example, in the Sonoran Desert, buffelgrass invasion coupled with frequent fire has converted desertscrub to non-native grassland in Mexico (Búrquez et al. 2002), created fuels sufficient to carry fire in Arizona, and recently appeared in southeastern California (M. Brooks personal observation). Land managers who once lamented the damage caused by fires fueled by red brome in southern Arizona are even more concerned now about the potential effects of buffelgrass (S. Rutman, Organ Pipe Cactus National Monument, personal communication). Buffelgrass is currently being considered for addition to the Arizona Department of Agriculture, Noxious Weed List, due primarily to its ability to alter fire regimes (E. Northam, personal communication). Thus, fine fuels management should be closely tied to invasive plant management, because the predominant plant invaders in the southern part of the desert bioregion are relatively flammable herbaceous species (Brooks and Esque, 2002). This is important both from the perspective of managing invasive plant fuels that are currently present, and preventing the establishment of new invasive plants that may

change fuel structure and potentially cause even greater fire management problems in the future.

Livestock grazing has been mentioned as a possible tool for managing fine fuels in the desert bioregion (Brooks et al. 2003, Minnich 2003). It may temporarily reduce fine fuel loads, and be effective for managing fuels in specific areas such as within the wildland urban interface. However, grazing may also reduce cover of late seral native plants and replace them with non-native annual and other early seral plant species (Brooks et. al 2003) that can be more flammable. Grazing treatments must be applied with attention to the potential responses of all dominant plant species, both in the short term based on the phenologic stage during which they are grazed, and in the long term based on their life history characteristics and inter-relationships among species.

Woody fuel management

Where native plant cover is sufficient to carry fire without the addition of fine fuels from non-native plants, coarse woody fuels are the major concern of fire managers. In the central and southern parts of the desert bioregion, blackbrush intermixed with perennial grasses, Joshua trees, and juniper produce the right mix of high fuel continuity, fuel loads, and fuel packing ratio that can cause large intense fires with frequent spotting ahead of the flaming front. Although infrequent, intense, stand-replacing fires are a natural part of blackbrush shrubland ecology, these types of fires are not desirable when they occur near human habitations, or where they may damage cultural resources such as historical buildings or pre-historical sites. Once these fires start, they often require indirect firefighting tactics to suppress, which complicates efforts to protect specific areas from burning. As a result, land managers and scientists are testing ways to reduce the chances of extreme fire behavior in this vegetation type where it occurs between Joshua Tree National Park and the communities of Yucca Valley and Joshua Tree (M. Brooks et al., unpublished data). They are comparing the effects of fire and mechanical blackbrush thinning on subsequent fuel conditions, fire behavior, and plant community structure. The goal is to find tools that will allow managers to manipulate fuel characteristics to reduce fire hazards near areas identified for protection from fire, while having minimal negative ecological effects, such as increased dominance of invasive non-native plants.

Sagebrush and pinyon-juniper fuels are the primary focus of fuel management in the northern parts of the desert bioregion, especially in the Mono section. Sagebrush intermixed with perennial grasses is generally considered to be a greater fire hazard than the blackbrush communities described above. A century or more of fire exclusion, livestock grazing, and climate change can also result in encroachment by pinyon-juniper woodlands into sagebrush steppe (Miller and Tausch 2001). This has been documented in the northeast bioregion of California (Schaefer et al. 2003), and has also occurred where rainfall is relatively high in the desert bioregion at the ecotone of the Great Basin desert with the Sierra Nevada Mountains (Anne Halford, botanist, BLM-Bishop Field Office). Dense stands of mature trees in that area increase the chance of intense, stand-replacing, crown fire. Unfortunately, these same mature woodlands are desirable for use as homesites, especially in the Mono section, complicating the implementation of fuels management treatments and the protection of homes during fires. Millions of hectares are

planned for fuels reduction in the western United States (http://www.fireplan.gov), and much will involve thinning of smaller size classes of pinyon and juniper trees to allow surface fuels to increase, and moderate intensity surface fires to return to the ecotone between pinyon-juniper woodlands and sagebrush steppe. Because very little is known about the effectiveness of these treatments in changing fire behavior or the potential ecological effects of these treatments, a research project was recently begun to quantify the effects of pinyon and juniper thinning on subsequent fuel condition, fire behavior, and ecosystem variables at a site in northwestern Arizona (M. Brooks et al., unpublished data).

Where sagebrush and pinyon-juniper vegetation interface in the southern desert sections, they are either at high elevations far from major roads and human habitations, or they contain surface fuels of insufficient amount and continuity to carry fire. These stands only burn under extreme fire weather conditions. Analyses of aerial photographs and VTM survey data from the 1930s show no evidence of pinyon-juniper expansion in the southern parts of the California desert region (R. Minnich, unpublished data). Accordingly, management of pinyon-juniper fuels is not advisable in this region, except were needed for specific cultural resource or safety reasons.

Fire Suppression

There is specific concern about the effect of fire suppression activities on the federally threatened desert tortoise where it occurs in low and middle elevation zones (Sidebar 16.3, this volume). More generally, fire suppression in desert wilderness areas became a significant issue after the California Desert Protection Act (1994) applied this designation to many new areas. Wilderness areas often encompass mountain ranges in the desert bioregion, where locally high fuel loads from both native and non-native plants, and steep slopes, facilitate the spread of fire. Fire suppression options are generally more limited in these areas by the constraints outlined in wilderness management plans, and often the primary tactic is to wait for fire to spread down slope and attempt to stop it along pre-existing roads. This can result in large portions of desert mountain ranges burning during a single event. The question is, which causes greater ecological damage, activities associated with aggressive fire fighting (e.g. construction of hand or bulldozer control lines, fire retardant drops) or large-scale, sometimes recurrent, fire occurring where fires were historically small and infrequent? We recommend that suppression be a high priority where fire frequency has been recently high in regional hotspots and non-native grass fire cycles have become locally established (Brooks and Esque 2002), where local populations of non-native plants may be poised to expand their range and landscape dominance following fire (mostly in the middle elevation ecological zone), or where there are other management reasons to exclude fire. Otherwise, a let burn policy for natural fires may be appropriate.

Postfire Restoration

Burn Area Emergency Rehabilitation (BAER) teams have developed postfire restoration/rehabilitation plans after the large fires that have recently occurred in the Mono section (e.g. Cannon and Slinkard fires), and further south in the desert bioregion at its ecotone with the Transverse and Peninsular ranges (e.g. the Juniper Complex and Willow fires). Much of this effort is focused on protecting watersheds from soil erosion, and one of the common tools is the seeding of rapidly growing plants (Sidebar 20.1, this volume). In general, seeding treatments establish more readily in the cold deserts than in the hot deserts, although relative establishment rates and the ecological effects of seeding in these two regions have not been experimentally compared.

Postfire seeding may also be used to compete with and reduce the cover of invasive grasses associated with the grass-fire cycle (Sidebar 16.1, this volume). The idea is to replace highly flammable species such as cheatgrass with less flammable seeded species. Non-native perennial grasses such as crested wheatgrass (*Agropyron desertorum*) have been used to compete with and reduce cover of cheatgrass in Great Basin sagebrush steppe. However, there has been a recent move toward using native species in postfire seeding, which may not have the same effect as non-native perennial grasses in suppressing the growth of non-native annual grasses such as cheatgrass. A current study is evaluating the relative effectiveness of non-native versus native perennial grasses to compete with and reduce cover of cheatgrass after fires in sagebrush steppe in the Mono section, and at sites in the Great Basin and Colorado Plateau (M. Brooks, unpublished data).

Fire Management Planning

One of the biggest challenges in fire management planning is determining desired future conditions to use as management goals. In cases where historical fire regimes can be reconstructed (e.g. ponderosa pine forest), the natural range and variation of historical fire regime characteristics may be a realistic and appropriate target. However, management goals may be elusive where historical fire regimes cannot be easily reconstructed, such as in the desert bioregion where one must rely on indirect inferences.

Fire histories alone may not be enough to establish management goals when protection of specific natural or cultural resources are the primary management goal, or where plant invasions have changed the rules of the game. For example, if plant invasions have shifted fuel characteristics outside of their natural range of historical variation, then restoration of historical fire regimes may be impossible without first dealing with the invasive plants that are at the root of the problem (Brooks et al. 2004). Although it appears that fire regimes, and at least woody fuel conditions, across much of the desert bioregion may be within their historical range of variation, it is difficult to quantify the impact that non-native plant invasions have had, aside from recognizing that fire regimes have been altered dramatically in some regional hotspots (Brooks and Esque 2002). Further complicating this process are the effects of potential future changes in rainfall patterns (Hereford et al. in press), and levels of atmospheric CO^2 (Mayeaux et al. 1994) and

nitrogen deposition (Brooks 2003), on fuel conditions and fire regimes. All of these potential variables need to be considered when determining fire management goals in the desert bioregion.

The recent mandate by federal land management agencies to create fire management plans for all management units has resulted in a flurry of activity as new plans are drafted and old plans are revised. In many cases, plans developed for desert management units are supported by relatively few scientific studies, due to the paucity of fire research that has been conducted in the desert regions of North America. Decisions on when and where fuels should be managed, fires should be suppressed or allowed to burn, or post-fire restoration projects should be implemented, are difficult to make given the limited data available. Recent reviews have attempted to provide land managers and others with current information on desert fire ecology and management (Brooks and Pyke 2001, Brooks and Esque 2002, Esque and Schwalbe 2002, Esque et al 2002, Brooks et al. 2003). Along these same lines, a primary purpose of this desert bioregion chapter is to provide additional information that can be used in the development of fire management plans in the deserts of southwestern North America.

Literature Cited

Bates, P.A. 1984. The role and use of fire in blackbrush (*Coleogyne ramosissima* Torr.) communities in California. Doctoral dissertation, University of California, Davis. 56 pp.

Bowns, J.E. 1973. An autecological study of blackbrush (*Coleogyne ramosissima* Torr.) in southwestern Utah. Doctoral dissertation, Utah State University, Logan. 115 pp.

Brooks, M.L 1999. Alien annual grasses and fire in the Mojave Desert. Madroño. 46:13-19.

Brooks, M.L. 2000. Schismus arabicus Nees, Schismus barbatus (L.) Thell. Pages 287-291 *in* C. Bossard, M. Hoshovsky, and J. Randall (eds.), Invasive Plants of California's Wildlands. University of California Press. Berkeley, CA.

Brooks, M.L.2002. Peak fire temperatures and effects on annual plants in the Mojave Desert. Ecological Applications 12:1088-1102.

Brooks, M.L. 2003. Effects of increased soil nitrogen on the dominance of alien annual plants in the Mojave Desert. Journal of Applied Ecology. 40:344-353.

Brooks, M.L. C.M. D'Antonio, D.M. Richardson, J. Grace, J. J. Keeley, DiTomaso, R. Hobbs, M. Pellant, D. Pyke. 2004. Effects of invasive alien plants on fire regimes. BioScience 54:677-688.

Brooks, M.L., and T.C. Esque. 2002. Alien annual plants and wildfire in desert tortoise habitat: status, ecological effects, and management. Chelonian Conservation and Biology 4:330-340.

Brooks, M.L., T.C. Esque, and T. Duck. 2003. Fuels and fire regimes in creosotebush, blackbrush, and interior chaparral shrublands. Report for the Southern Utah Demonstration Fuels Project, USDA, Forest Service, Rocky Mountain Research Station, Fire Science Lab, Missoula, Montana. 17pp.

Brooks, M.L. and J.R. Matchett. 2003. Plant community patterns in unburned and burned blackbrush (*Coleogyne ramosissima*) shrublands in the Mojave Desert. Western North American Naturalist 63:283-298

Brooks, M.L., J.R. Matchett, and K.Berry. In press. Alien and native plant cover and diversity near livestock watering sites in a desert ecosystem. Journal of Arid Environments.

Brooks, M.L. and D. Pyke. 2001. Invasive plants and fire in the deserts of North America. Pages 1-14 *in* K. Galley and T. Wilson (eds.), Proceedings of the Invasive Species Workshop: The Role of Fire In the Control and Spread of Invasive Species. Fire Conference 2000: The First National Congress on Fire, Ecology, Prevention and Management. Miscellaneous Publications No. 11, Tall Timbers Research Station, Tallahassee, Florida, USA

Brown, D.E. 1984. Fire and changes in ceososte bush scrub on the western Colorado Desert, California. Master's of Science Thesis, University of California, Riverside.

Brown, D. E. and R. A. Minnich. 1986. Fire and creosote bush scrub of the western Sonoran Desert, California. American Midland Naturalist 116:411-422.

Brown, J.K. and J.K. Smith. eds. 2000. Wildland fire in ecosystems: effects of fire on flora. Gen. Tech. Rep. RMRS-GTR-42-vol. 2. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 257 p.

Brown, T.J., B.L. Hall, C.R. Mohrle, and H.J. Reinbold. 2002. Coarse assessment of federal wildland fire occurrence data. CEFA Report 02-04. Desert Research Institute, Division of Atmospheric Sciences, Reno, Nevada.

Búrquez, A.M., A.Y. Martinez, M. Miller, K. Rojas, M.A. Quintana, and D. Yetman. 1996. Mexican grasslands and the changing arid lands of Mexico: and overview and a case study in northwestern Mexico. Pp. 21-32. in B. Tellman, D.M. Finch, E. Edminster, and R. Hamre (eds). The futue of arid grasslands: identifying issues, seeking solutions, Proceedings RMRS-P-3. U.S. Forest Service, Rocky Mountain Station, Fort Collins, Colorado.

Dalton, P.D. 1962. Ecology of the creosotebush Larrea tridentate (D.C.) Cov. Doctoral Dissertation, University of Arizona.

De Soyza, A.G., W.G. Whitford, E. Martinez-Meza, and J.W. Van Zee. 1997. Variation in creosotebush (Larrea tridentate) canopy morphology in relation to habitat, soil fertility, and associated annual plant communities. American Midland Naturalist 137:13-26.

D'Antonio, C. M. and P. M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 3:63-87.

Esque, T.C., A.M. Búrquez, C.R.Schwalbe, T.R. VanDevender, M.J.M. Nijhuis, and P. Anning. 2002. Fire ecology of the Sonoran desert tortoise. Pages 312-333 *in* The Sonoran Desert Tortoise: Natural History, Biology, and Conservation. Arizona-Sonora Desert Museum and the University of Arizona Press, Tuscon, Arizona.

Esque, T.C. and C.R. Schwalbe. 2002. Alien annual plants and their relationships to fire and biotic change in Sonoran desertscrub. Pages 165-194 *in* Tellman, B.(ed.).

Invasive exotic species in the Sonoran region. Arizona-Sonora Desert Museum and the University of Arizona Press, Tuscon, Arizona.

Esque, T.C., C.R. Schwalbe, L.A. DeFalco, T.J. Hughes and R.B. Duncan. 2003. Effects of wildfire on small desert vertebrates, especially desert tortoises (*Gopherus agassizii*). The Southwestern Naturalist. In press.

Hereford, R., R.H. Webb, R.H., C.I. Longpré. In press. Precipitation history and ecosystem response to multidecadal precipitation variability in the Mojave Desert region, 1893-2001. Journal of Arid Environments.

Humphrey, R. R. 1974. Fire in deserts and desert grassland of North America. Pages 365-401 *in* T. T. Kozlowski and C. E. Ahlgren (eds.) Fire and Ecosystems. Academic Press, New York.

Hunter, R. 1991. *Bromus* invasions on the Nevada Test Site: present status of *B. rubens* and *B. tectorum* with notes on their relationship to disturbance and altitude. Great Basin Naturalist 51:176-182.

Koehler, P.A., R.S. Anderson, and W.G. Spaulding. 2005. Development of vegetation in the central Mojave Desert of California during the late Quaternary. Paleogeography, Paleoclimatology, Paleoecology 215:297-311.

Küchler 1964. Potential natural vegetation of the conterminous United States. Special Pulblication 36, American Geographical Society, New York, New York.

Mayeaux, H. S., H. B. Johnson, and H.W. Polley. 1994. Potential interactions between global change and Intermountain annual grasslands. In: Monsen, S.B., and Kitchen, S. G. (Eds.), Proceedings of Ecology and Management of Annual Rangelands. Ogden, Utah: Intermountain Research Station, pp. 95-110.

Miles, S.R. and C.B. Goudy. 1997. Ecological subregions of California: Section and subsection descriptions. USDA Forest Service, R5-EM-TP-005.

Miller, R.F., and R. J. Tausch. 2001. The role of fire in juniper and pinyon woodlands: as descriptive analysis. Pages 15-30 *in* K. Galley and T. Wilson (eds.), Proceedings of the Invasive Species Workshop: The Role of Fire In the Control and Spread of Invasive Species. Fire Conference 2000: The First National Congress on Fire, Ecology, Prevention and Management. Miscellaneous Publications No. 11, Tall Timbers Research Station, Tallahassee, Florida, USA

Minnich, R.A. 1988. The biogeography of fire in the San Bernardino Mountains of California. University of California Publications in Geography 28:1-121.

Minnich, R.A. 2003. Fire and dynamics of temperate desert woodlands in Joshua Tree National Park. Report submitted to the National Park Service, Joshua Tree National Park. Contract number P8337000034/0001. 32 pp.

Minnich, R.A. and R.G. Everett. 2001. Conifer tree distributions in southern California. Madrono 48, 177-197.

Minnich, R.A. and A.C. Sanders. 2000. Brassica tournefortii (Gouan). Pages 68-71 *In* C. Bossard, M. Hoshovsky, and J. Randall (eds.). Invasive Plants of California's Wildlands. University of California Press. Berkeley, CA.

Munz and Keck, 1959. A California Flora. University of California Press, Berkeley, California. 1681 pp.

O'Leary, J. F. and R. A. Minnich. 1981. Postfire recovery of creosote bush scrub vegetation in the Western Colorado Desert. Madroño 28:61-66.

Rogers, G. F. and M. K. Vint. 1987. Winter precipitation and fire in the Sonoran Desert. Journal of Arid Environments 13:47-52.

Rowlands, P.G. 1980. The vegetational attributes of the California Desert Conservation Area. pp. 135-183. *In* J. Latting (ed.). The California desert: an introduction to its resources and man's impact. California Native Plant Society Special Publication 5.

Schaefer, R.J., D.J. Thayer, and T.S. Burton. 2003. Forty-one years of vegetation change on permanent transects in northeastern California: implications for wildlife. California Fish and Game 89:55-71.

Schmid, M. K. and G. F. Rogers. 1988. Trends in fire occurrence in the Arizona upland subdivision of the Sonoran Desert, 1955 to 1983. The Southwestern Naturalist 33:437-444.

Schmidt, K.M., J.P. Menakis, C.C. Hardy, W.J. Hann, and D.L. Bunell. 2002. Development of Coarse-Scale Spatial Data for Wildand Fire and Fuel Management. United States Department of Agriculture, Forest Service, General Technical Report, GTR-RMRS-87.

Van Devender, T.R. and W.G. Spaulding. 1979. Development of vegetation and climate in the southwestern United States. Science 204:701-710.

van Wagtendonk, J. W., and D. Cayan. In press. Temporal and spatial distribution of lightning strikes in California in relationship to large-scale weather patterns. Fire Ecology.

Wangler, M. and R.A. Minnich. 1996. Fire and succession in pinyon-juniper woodlands of the San Bernardino Mountains. Madroño 43:493-514.

Webb, R.H., J.W. Steiger, and E.B. Newman. 1988. The response of vegetation to disturbance in Death Valley National Monument, California. U.S. Geological Survey Bulletin 1793.

White, L.D. 1968. Factors affecting the susceptibility of creosotebush (*Larrea tridentata* (D.C.). Cov.) to burning. Doctoral Dissertation, University of Arizona.

Whisenant, S. G. 1990. Changing fire frequencies on Idaho's snake river plains: ecological and management implications. Pages 4 -7 *in* E. D. McArthur, E. D. Romney, E. M. Smith, and S. D. Tueller (eds.). Proceedings - Symposium on Cheatgrass Invasion, Shrub Die-off, and Other Aspects of Shrub Biology and Management, 5–7 April 1989, Las Vegas, NV. General Technical Report INT-276, Department of Agriculture, Forest Service, Intermountain Research Station.

Wright, H.E. and A.W. Bailey. 1982. Fire Ecology, United States and Canada. Wiley, New York.

SIDEBAR 16.1. Ecological Effects of Non-native Annual Grasses

by Matthew Brooks and Richard Minnich

Non-native annual grasses in the genera *Bromus*, *Avena*, and others have become dominant components of many grasslands, shrublands, woodlands, and forests in western North America during the 20th century. These invasions have negatively affected native plant species by directly competing with them for limiting soil nutrients and water, and by altering ecosystem properties such as fuel characteristics and fire regimes. The positive feedback between non-native grass dominance and increased fire frequency, or the "grass/fire cycle" (D'Antonio and Vitousek 1992), is the most clearly understood and well-documented example of the more general "invasive plant/fire regime cycle" (Brooks et al. 2004).

Fire frequencies that have increased beyond their historical range and variation can have dramatic and far-reaching ecological effects. For example, invasion of the non-native cheatgrass (*Bromus tectorum*) has altered fuelbed characteristics and shortened fire return intervals from 30 to 100 years to 5 years in areas of the Great Basin (Whisenant 1990). This new fire regime promotes the dominance of cheatgrass over native species, resulting in large-scale conversions of high diversity, native sagebrush steppe to low diversity, non-native annual grassland. This vegetation change has negatively affected animals that require sagebrush steppe for forage and cover such as the sage grouse (*Centrocercus urophasianus*) (Sidebar 11.2, this volume), and prey species such as black-tailed jackrabbits (*Lepus californicus*) and the Paiute ground squirrel (*Spermophilus mollis*) which are important for golden eagles (*Aquila chrysaetos*) and prairie falcons (*Falco mexicanus*) (Knick and Rotenbery 1995, Knick et al 2003). Although similar large-scale higher-order effects have not been documented in the Mojave, Colorado, or Sonoran deserts, non-native grass/fire cycles have degraded habitat for the desert tortoise (*Gopherus agassizii*) in localized hotspots within these desert regions (Brooks and Esque 2002, Sidebar 16.3 this volume).

Invasive plant/fire regime cycles represent ecosystem shifts to alternative stable states which will likely persist unless fuels, climate, or ignition patterns significantly change (Brooks et al. 2004). For example, non-native annual grasses such as cheatgrass and medusahead (*Taeniatherum caput-medusea*) persist in cold desert regions like the Great Basin because rainfall is typically sufficient to support reproduction during any given year. Although the fuelbeds they create may only significantly affect fire behavior following years of high rainfall, their populations will likely persist even during years of low rainfall. As a result, non-native grasses and the altered fire regimes they cause are now relatively permanent features in many parts of the cold desert region.

In contrast, the hot desert regions of the Mojave, Colorado, and Sonoran deserts receive less annual rainfall than the cold desert regions, increasing the chances of population crashes of non-native annual grasses such as cheatgrass and red brome (*Bromus rubens*). Rainfall events as small as 5 mm (2 in) can stimulate their germination, and when there is little subsequent rainfall, the plants often die before reproducing (M. Brooks and R. Minnich, personal observations), potentially depleting the soil seedbank. This is probably why red brome became locally extinct at two low elevation desert sites after the late 1980s drought, and at one low elevation site after the late 1990s drought (R Minnich, unpublished

data). However, extirpation of red brome did not occur at many higher elevation desert sites following these same drought periods (M. Brooks, personal observation). Broad-scale responses by non-native grasses to droughts indicate that they are typically not regionally extirpated and can recover to ecologically significant numbers relatively quickly in hot desert regions. For example, after the end of the approximately 30-year mid-century drought (Hereford et al. in press) red brome density and biomass jumped 700% and 150% respectively between the last year of the drought (1975) and the first year of higher rainfall (1976), and by 1988 the increase above 1975 levels reached 15,646% for density and 1,596% for biomass at a Mojave Desert/Great Basin ecotone in southern Nevada (Hunter 1991). During this time interval, density and biomass of native annuals decreased (Hunter 1991), while the frequency and size of fires across the Mojave Desert steadily increased (Brooks and Esque 2002,). In addition, the shorter 1987-1991 drought was followed in 1993 by one of the biggest fire years in the 1980-2001 agency fire record for the hot desert regions, and the spread of many of these fires was facilitated by substantial fine fuebeds of red brome and cheatgrass.

Thus, non-native annual grasses will not likely ever become extirpated from the hot desert regions under the current climate regime, although their landscape dominance and effects on fire frequency and behavior will undoubtedly continue to be highly episodic in response to rainfall. Non-native grass/fire cycles have already become established in some localized hotspots within the hot desert region (Brooks and Esque 2002). The extent of area affected by these vegetation and fire regime type-conversions may expand during periods of high rainfall in the future, although most of this expansion will probably be confined to the middle elevation desert shrubland and grassland ecological zone. Below the middle elevation zone, extreme drought conditions will cause more frequent population crashes of red brome and cheatgrass and thus limit their influence on fire regimes, and above the middle elevation zone native woody plants and perennial grasses are the primary factors affecting fire regimes.

Brooks, M.L 1999. Alien annual grasses and fire in the Mojave Desert. Madroño. 46:13-19.

Brooks, M.L. C.M. D'Antonio, D.M. Richardson, J. Grace, J. J. Keeley, DiTomaso, R. Hobbs, M. Pellant, D. Pyke. 2004. Effects of invasive alien plants on fire regimes. BioScience 54:677-688.

Brooks, M.L., T.C. Esque, and T. Duck. 2003. Fuels and fire regimes in creosotebush, blackbrush, and interior chaparral shrublands. Report for the Southern Utah Demonstration Fuels Project, USDA, Forest Service, Rocky Mountain Research Station, Fire Science Lab, Missoula, Montana. 17pp.

Brooks, M.L., and T.C. Esque. 2002. Alien annual plants and wildfire in desert tortoise habitat: status, ecological effects, and management. Chelonian Conservation and Biology 4:330-340

D'Antonio, C. M. and P. M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 3:63-87.

Hereford, R., R.H. Webb, and … In press. Climate variation and vegetation response in the Mojave Desert. Journal of Arid Environments.

Hunter, R. 1991. *Bromus* invasions on the Nevada Test Site: present status of *B. rubens* and *B. tectorum* with notes on their relationship to disturbance and altitude. Great Basin Naturalist 51:176-182.

Knick, ST, DS Dobkin, JT Rotenberry, MA Schroeder, WM Vander Hagen, and C Van Riper III. 2003. Teetering on the edge or too late? Conservation and research issues for avifauna of sagebrush habitats. The Condor *In Press*.

Knick, S.T. and J.T. Rotenberry. 1995. Landscape characterisitics of fragmented shrubsteppe habitats and breeding passerine birds. Conservation Biology 9:1059-1071.

Whisenant, S. G. 1990. Changing fire frequencies on Idaho's snake river plains: ecological and management implications. Pages 4 -7 *in* E. D. McArthur, E. D. Romney, E. M. Smith, and S. D. Tueller (eds.). Proceedings - Symposium on Cheatgrass Invasion, Shrub Die-off, and Other Aspects of Shrub Biology and Management, 5–7 April 1989, Las Vegas, NV. General Technical Report INT-276, Department of Agriculture, Forest Service, Intermountain Research Station.

SIDEBAR 16.2. Saltcedar Invasions Can Change Riparian Fire Regimes

by Tom Dudley and Matthew Brooks

Saltcedar (*Tamarix ramossissima*) was brought to North America in the early 1800's by European colonists as a horticultural plant, and by the early 1900's it became widely used to provide windbreaks and erosion control along railways and other erosion-prone sites. Its ability to tolerate periodic drought and harsh soil conditions helped insure its establishment persistence where other species failed. It was recognized as an invader of desert watercourses around the 1920's, and with the advent of water control and diversion projects took advantage of the altered conditions to expand its range during the middle and latter part of the century (Robinson 1965).

Saltcedar is deciduous and produces a fine-structured, water-repellent litter layer that is highly flammable in late summer and fall. Because stand densities can be very high, and litter is slow to decompose, a nearly-continuous layer of surface fuels can develop which carries fire throughout the stand (Busch and Smith 1992). The standing trees are also flammable, and can carry fire from surface fuels up into the canopies of native riparian trees. These fuel characteristics can create a frequent, high intensity, crown fire regime where an infrequent, low to moderate intensity, surface fire regime previously existed. After burning, saltcedar stump-sprouts readily and benefits from nutrients released by fire, whereas native riparian plants such as cottonwood and willow do not resprout as vigorously (Ellis 2001). Recurrent high intensity fire may lead to monoculture stands of saltcedar. Thus, saltcedar has turned many watercourses from barriers of fire movement to pathways for fire spread.

As stands of saltcedar increase in density and cover, native cottonwood and willow trees decrease. In some cases this is coincident with changing environmental conditions that do not favor the native species (e.g. decreased water tables caused by water diversion projects; Everitt 1998), but in other cases it is clear that saltcedar is responsible for the

decline in native trees, directly through competition and indirectly through altered fire regimes (Busch and Smith 1995). Because it provides lower quantity and quality of shade, forage, and insect prey species, wildlife generally avoid large stands of saltcedar in preference for native stands (Shafroth et al. in press). This includes numerous threatened and declining riparian birds which find better nesting and feeding resources on native trees. In addition, saltcedar can have higher evapotransporation rates than native trees, potentially reducing water tables (Sala et al. 1996). All of these symptoms of saltcedar invasion have caused major management problems in southwestern riparian ecosystems.

Mechanical and chemical methods are typically used to manage saltcedar, however they can be very expensive ($300 - $6,000/ha.; Shafroth et al. in press), their effectiveness is often limited and temporary, and they can have other undesirable ecosystem effects. After more than a decade of pre-release testing, a leaf-feeding beetle from Eurasia, *Diorhabda elongata*, has been experimentally released in several western states as a biological control agent against saltcedar (Dudley et al. 2000). At one site in northern Nevada this beetle defoliated approx. 2 ha in 2002, and spread to defoliate over 400 ha in 2003. The physiological stress experienced by defoliated plants may lead to lowered live fuel moisture, and definitely increases the amount of dead wood and foliage. In the short term, this biocontrol may increase the chance of high-intensity fire, but in the long run the conversion of saltcedar stands back to native riparian woodlands will likely reduce fire hazards.

Busch, D.E. and S.D. Smith. 1992. Fire in a riparian shrub community: postburn water relations in the *Tamarix-Salix* association along the lower Colorado River. Pages 52-55 in W.P.Clary, M.E. Durant, D. Bedunah and C.L. Wambolt (comp.), Proc. Ecology and management of riparian shrub communities. USDA-FS GTR-INT-289.

Busch, D.E. and S.D. Smith. 1995. Mechanisms associated with decline of woody species in riparian ecosystems of the southwestern U.S. Ecol. Monogr. 65:347-370.

Dudley, T.L., C.J. DeLoach, J.E. Lovich and R.I. Carruthers. 2000. Saltcedar invasion of western riparian areas: impacts and new prospects for control. Pages 345-381 In R.E. McCabe and S.E. Loos (eds) Tran. 65th No. Amer. Wildlife Mgt. Inst., Washington, D.C.

Ellis, L.M. 2001. Short-term response of woody plants to fire in a Rio Grande riparian forest. Biol. Cons. 97:159-170.

Everitt, B.L. 1998. Chronology of the spread of tamarisk in the central Rio Grande. Wetlands 18:658-668.

Robinson, T.W. 1965. Introduction , spread and areal extent of saltcedar (*Tamarix*) in the western states. USGS Prof. Paper 491-A.

Sala, A., S.D. Smith and D.A. Devitt. 1996. Water use by *Tamarix ramosissima* and associated phreatophytes in a Mojave Desert floodplain. Ecol. Applic. 6:888-898.

Shafroth, P.B., J.R. Cleverly, T.L. Dudley, J.N. Stuart, J.P. Taylor C. van Riper and E.P. Weeks. Saltcedar removal, water salvage, and wildlife habitat restoration along rivers in the southwestern U.S. Frontiers in Ecology (In press).

SIDEBAR 16.3. Fire Effects on the Desert Tortoise (Gopherus agassizii)

by Matthew Brooks and Todd Esque

Changing fire regimes threaten 12 of the 40 major tortoise species worldwide (Swingland and Klemens 1989). Only general habitat destruction is listed as a threat for more species (23 of 40 species). In general, tortoises are poorly adapted to fire because they evolved in arid or semi-arid habitats where fire was historically rare. The desert tortoise (*Gopherus agassizii*), Mojave population, is a Federally Threatened species listed partly because of threats posed by fire.

Fires can kill desert tortoises, especially fires that occur in the spring and early summer when they are most active above-ground throughout their range (Esque et al. 2002). Years of high rainfall produce the profuse annual plant growth that is required for desert tortoise reproduction, but it also contributes to fire occurrence, especially at the low and middle elevation zones within the desert tortoise range. Thus, years when growth and reproduction are expected to be greatest can be coincident with increased fire occurrence. Although, mortality from individual fires is generally considered insignificant for wildlife populations compared to the habitat changes that can follow, loss of a few individuals may be catastrophic for local populations of species that are already in decline (Esque et al. 2003).

Fires can also affect desert tortoises indirectly, by changing habitat structure and plant species composition. Loss of cover sites that provide protection from the sun and predators, and loss of native forage plants are specific examples of the potential negative effects of fire (Brooks and Esque 2002, Esque et al. 2002). Individual fires may have relatively small indirect effects within desert tortoise habitat, since they are often patchy, leaving unburned islands of native vegetation. In contrast, recurrent fires pose a much greater threat, as they often burn through previously unburned islands of vegetation, and can produce broad landscapes devoid of shrub cover and dominated by non-native annual grasses. These conditions are currently focused within a number of regional hotspots in the desert bioregion (Brooks and Esque 2002).

When fighting fires that occur within desert tortoises habitat in the low and middle elevation zones, land managers follow guidelines developed to reduce the chance of killing desert tortoises such as not burning out unburned habitat islands when feasible, checking under tires before moving vehicles, and walking ahead of vehicles when they are required to travel off-road (Duck et al. 1998). Results of firefighting activities in desert tortoise habitats have proven that the benefit of fighting fires in desert tortoise habitat far outweighs the potential danger of damage to habitats and tortoise populations when appropriate guidelines are followed (Duck et al. 1998).

Brooks, M.L., and T.C. Esque. 2002. Alien annual plants and wildfire in desert tortoise habitat: status, ecological effects, and management. Chelonian Conservation and Biology 4:330-340.

Duck, T.A., T.C. Esque, and T.J. Hughes. 1997. Fighting wildfires in desert tortoise habitat, Considerations for land managers. Proceedings for Symposium on: Fire Effects on Rare and Endangered Species Habitats Conference. November 13-16, 1995. Coeur D'Alene, ID. International Wildland Fire Association.

Esque, T.C., A. Burquez M., C.R. Schwalbe, T.R. Van Devender, P.J. Anning, and M.J. Nijhuis. 2002. Fire Ecology of the Sonoran Desert Tortoise. *In* The Sonoran Desert tortoise: Natural History Biology and Conservation. T.R. Van Devender, *ed*. The University of Arizona Press and The Arizona-Sonora Desert Museum. Tucson. Pp. 312-333.

Esque, T.C., C.R. Schwalbe, L.A. DeFalco, T.J. Hughes and R.B. Duncan. 2003. Effects of wildfire on small desert vertebrates, especially desert tortoises (*Gopherus agassizii*). *The Southwestern Naturalist* 48:103-110.

Swingland, I.R. and Klemens, M.W. 1989. The Conservation Biology of Tortoises. Occasional Papers of the IUCN Species Survival Commission (SSC), No. 5. Gland, Switzerland: International Union for Conservation of Nature and Natural Resources, 204pp.

THE EFFECTS OF WILDFIRE ON REPTILE POPULATIONS

IN THE MOJAVE NATIONAL PRESERVE, CALIFORNIA

Final Report
January 2009

Prepared By:
Kirsten E. Dutcher
California State University, Long Beach

ACKNOWLEDGEMENTS

I cannot express enough appreciation for the generous funding provided by the California Desert Research Fund at the Community Foundation, the California Desert Studies Consortium, and California State University. Also, to the Desert Studies Center at Zzyzx, for use of equipment and facilities.

I would also like to thank the individuals at the Mojave National Preserve who made this research possible, particularly David Nichols and Debra Hughson. Also, my advisor Dr. James W. Archie who introduced me to the study area and supported my research decisions. My sincere gratitude goes to Dr. Dessie Underwood, Dr. Esteban Fernandez-Juricic, Dr. Simon Malcomber, Dr. Lynn Zimmerman, Terry Christopher, and Alicia Fox for assistance with experimental design and proofreading.

I am grateful to Marcello Aguirre, Matt Baxter, James Dutcher, Robert Dutcher, Cristina Francois, Erin Guinn, Ashley Jones, Stephen Jones, Sara Louwsma, Jeff Putzi, Jim Toenjis, and members of the California Conservation Core for field assistance and willingness to work long hours on this project.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ii

LIST OF TABLES iv

LIST OF FIGURES v

ABSTRACT vi

INTRODUCTION 1
- Ecological Role of Wildfire 1
- Fragmentation, Wildfire, and Reptile Communities 1
- Wildfire and Exotic Plants in Desert Regions 2
- Wildfire in the Mojave Desert 2
- Objectives 2

MATERIALS AND METHODS 4
- Site Selection 4
- Temperature Data Collection 4
- Transect Design 4
- Vegetation Point-Intercept Transect Surveys 4
- Reptile Transect Surveys 5
- Pitfall Trapping 5
- Statistical Analysis 6

RESULTS 7
- Ambient Air, Ground Surface, and Subterranean Temperatures 7
- Vegetation Point-Intercept Transect Surveys 7
- Reptile Transect Surveys 8
- Pitfall Trapping 9

DISCUSSION 10
- Temperature and Vegetation 10
- Comparison of Transect and Pitfall Data 10
- Future Research Recommendations 10
- Conservation Implications 11

TABLES 12

FIGURES 19

LITERATURE CITED 25

LIST OF TABLES

1. Transect Locations in the Hackberry Region, Mojave National Preserve 12

2. Locations of Pitfall Trap Arrays in the Hackberry Region of the Mojave National Preserve 13

3. Percent Vegetation Cover in Unburned and Burned Habitats by Height Class 14

4. Reptile Species Observed During Transect Surveys 15

5. Reptile Species Captured During Pitfall Trapping 16

6. Mammal Species Captured During Pitfall Trapping 17

7. Invertebrate Families Captured During Pitfall Trapping 18

LIST OF FIGURES

1. Habitat patch locations within the Hackberry region of the Mojave National Preserve 19

2. Transect design 20

3. Pitfall array design 21

4. Ambient, ground, and subterranean temperatures ($\bar{x} \pm SD$) 22

5. Total number of *Uta stansburiana* observed during transect surveys in each habitat type by year 23

6. Total number of *Uta stansburiana* captured in pitfall traps moving into or out of habitat patches by year 24

ABSTRACT

During the summer of 2005, lightning caused wildfires in the Mojave National Preserve, California. The fires burned 287 km^2 and left unburned patches surrounded by burned vegetation.

This study examined the effects of the wildfires on reptile diversity and *Uta stansburiana* (side-blotched lizard) abundance by conducting transect surveys at patches and along the fire perimeter in burned and unburned habitats. Temperature and vegetation cover data were recorded at each site. Pitfall trapping was conducted at patch sites to monitor *U. stansburiana* movements.

The wildfires resulted in higher temperatures in burned areas and more cover in unburned areas. Burned and unburned habitats had comparable reptile diversity and *U. stansburiana* was most abundant. *U. stansburiana* in unburned perimeter locations were constant, indicating this population was the least impacted. In 2006 the most were found along the burned side of the perimeter where high temperatures may have allowed for optimal basking sites. In 2007 the temperatures increased and the individuals in this area decreased by half.

The number of individuals moving out of patches was consistent but the number moving in increased, indicating a preference for unburned areas. The low numbers recorded in this study suggest that the wildfire negatively impacted the herpetological community.

INTRODUCTION

Ecological Role of Wildfire

Disturbance is common to all ecosystems and results in altered landscapes that differ from original habitat in floral and faunal composition and abundance (Reice, 2001). Natural disturbance, particularly wildfire, causes habitat changes by killing mature plants, seedlings, and seeds. Fire also alters the nutrient levels and water absorption abilities of soil. The effects of fire result in changes in microclimate, particularly post-fire soil temperature and moisture, and drastically reduce ground cover (Brooks, 2002; Odion and Davies, 2000).

In systems that are fire adapted this disturbance is essential for floral and faunal persistence (Parr and Chown, 2003). However, in areas that have not historically been subjected to frequent or intensive fire regimes, such as arid ecosystems, species diversity and abundance suffer due to mortality during the fire and the subsequent alteration of habitat (Brooks and Matchett, 2003; Taylor and Fox, 2001).

The unpredictable nature of wildfires often creates a habitat framework of small unburned patches within what was once contiguous habitat (Parr and Chown, 2003; Turner et al., 1997). Wildfire thus fragments habitat by creating small patches that are separated from one another by a habitat type that no longer resembles original conditions. Fragmentation due to wildfire does not necessarily indicate permanent habitat loss (Fahrig, 2003). The effects of wildfire are unpredictable and recovery is highly variable depending on location, burn severity, intensity, and post-fire plant succession (Davies et al., 2001; McKenzie et al., 2004; Reice, 2001; Turner et al., 1997).

Fragmentation, Wildfire, and Reptile Communities

A review of herpetofaunal response to fire found that many animals exhibit panic and experience high rates of mortality (Russell et al., 1999). Because of the need for thermoregulatory, foraging, and protected sites, reptiles are highly dependent on habitat structure and fire has been shown to reduce their abundance and limit movements (Setser and Cavitt, 2003; Valentine et al., 2007). However, unburned habitat patches may serve as refugia for reptile populations that survive in the patch, nearby rock outcroppings, or burrows in the ground (Faria et al., 2004; Friend, 1993).

While vegetated areas produce shaded microclimates where soil temperatures are less extreme and moisture is preserved, disturbed habitats generally show reduced vegetation complexity (Patten and Smith, 1975). Habitats dominated by invasive plants also show decreased numbers of invertebrates. This reduction in thermoregulatory and food resources results in a decrease in total reptile abundance. Studies in disturbed areas in southern California, Australia, and Egypt have indicated that reptile abundance and diversity were positively correlated with vegetation percent cover and native vegetation (Attum et al., 2006; Russell et al., 1999; Valentine et al., 2007).

Wildfire and Exotic Plants in Desert Regions

Historically, large wildfires in desert communities have been uncommon because without a relatively large, continuous fuel source, wildfires tend to have reduced size and intensity (Hanes, 1971; Reice, 2001). However, in North American deserts, wildfires have become increasingly frequent since the 1970s. This is because of the introduction of exotic plant species, particularly *Erodium cicutarium* (fillaree), *Bromus sp.* (foxtail, cheatgrass) and *Schismus sp*. (Mediterranean grass). These species, native to Europe, Africa, and Asia, are adapted to fire regimes in arid ecosystems and create a blanket of dry vegetation that facilitates the spread of wildfire by creating a layer of dry, fast burning fuel. Recurrent fire in the American southwest amplifies the presence of these alien species, which have been shown to replace long-lived natives, changing the floral composition (Brooks, 1999, 2000a, 2000b; Brooks and Matchett, 2003; Esque, 1999; Young, 2000). Because of these effects wildfire is currently considered one of the main threats to native species in the Mojave (Brooks, 2002).

Wildfire in the Mojave Desert

The Mojave Desert is subjected to frequent lightning strikes during the summer monsoon season (May-August) and wildfires are generally caused by dry lightning storms during this period (Esque et al., 2003). Large fires are infrequent events in areas with native vegetation. Consequently, wildfires in the Mojave have not been well studied, and their effects have yet to be well documented (National Park Service, 2003).

On 22 June 2005, a series of dry seasonal storms passed through the Mojave National Preserve (MNP), San Bernardino County, California. Dry lightning caused multiple fires that merged to become the Hackberry complex of wildfires. The fires burned for seven days and were contained on 28 June 2005. A total of 287 km^2 burned within the Preserve between elevations of 1097-2012 m (http://www.nps.gov/moja/ parkmgmt/upload/Hackberry_BAER_Plan%2006-05.pdf). Within the Hackberry region the dominant form of vegetation affected by the fires was juniper woodland (Mojave National Preserve Maps, 2005). However, the fire did not consume all of the vegetation and the burned landscape contained several patches of unburned habitat. These habitat islands were surrounded on all sides by burned vegetation resulting in a fragmentation of the habitat.

Objectives

The Mojave is home to an incredible array of reptiles and the Hackberry region supported many species. The objective of this study was to determine the effects of the Hackberry wildfires on the herpetofaunal community. Based on previous research, most of which indicates increased mortality as well as limited habitat utilization and movement following a wildfire, it was reasonable to expect populations in the Mojave would show similar responses. I expected to find increased ground and subterranean temperatures and decreased vegetation cover in burned areas, with cover increasing through time, but not

achieving pre-burn proportions or composition. The burned locations were expected to support fewer reptile species based on the resources available. As density increased with time, more individuals were expected to disperse from unburned habitat patch locations. I tested the hypothesis that movement into and out of unburned habitat patches by would change with time. I predicted that in the first year of this study more individuals would migrate into unburned habitat patches and that in the second year the individuals would disperse out of patches as lizard density and vegetation in burned areas increased.

MATERIALS AND METHODS

Site Selection

The Mojave National Preserve (MNP) lies in the eastern portion of the Mojave Desert of California. The Preserve is located to the south of Death Valley and north of Joshua Tree National Parks, between Interstates 15 and 40. The infrequency of large wildfires, remoteness of the area, and limited impact from development make the MNP an excellent area to study. Permits were obtained from the National Park Service, California Department of Fish and Game, and California State University (IACUC number 279).

Sampling for this study was concentrated in what was predominantly juniper woodland between the elevations of 1,370 m-1,675 m (Mojave National Preserve Maps, 2005). Sites were located near Cedar Canyon and Black Canyon roads, in the Mid-Hills area (Figure 1). Seven unburned habitat patches, that were surrounded by burned landscape on all sides, and seven perimeter locations along the fire edge were surveyed. Patch sites were mapped using a handheld Global Positioning System (GPS) unit and ranged in size from approximately 1,527-36,580 m^2.

Temperature Data Collection

Ambient, ground, and subterranean temperatures were collected using a handheld Ashcroft dial thermometer. All temperatures were recorded after the thermometer was placed in a temporarily shaded area for 2 minutes and collected at the start of each transect survey on both the burned and unburned sides. Air temperature was recorded after holding the thermometer several feet above the ground, ground temperature was recorded after placing the thermometer on the soil surface, and subterranean temperature was recorded after placing the tip of the thermometer 3-5 cm into the soil.

At one habitat patch an Eastman maximum/minimum thermometer was installed on a wooden stake 50 cm above the ground to determine air temperature extremes.

Transect Design

Transects were used to assess species diversity and abundance across distinct habitat types with clearly defined borders (Morris, 1995). At each sampling site three parallel transects that crossed the transition zone from burned into unburned habitat were monitored. Each transect was a straight-line 50 m in length, and bisected the habitat, with 25 m in each habitat type. Transects were separated from replicates by 20 m (Figure 2). Transects were measured out using a 25 m Lufkin tape measure. I used GPS waypoints to mark the start and end locations of each transect (Table 1).

Vegetation Point-Intercept Transect Surveys

Vegetation point-intercept transects were conducted by walking the transect lines described above and recording vegetation height every five meters. At each point a 7-cm

diameter pole was placed directly on the point and the height of each plant that touched recorded (Barbour et al., 1999). Plant height was classified as <10 cm, 10-30 cm, 30-50 cm, 50 cm-1 m, and >1 m. Dead or severely burned vegetation was not recorded. I recorded vegetation once a month from May-October 2006 and March-August 2007. A total of 504 vegetation transects were conducted (14 sites x 3 replicates x 12 times).

Reptile Transect Surveys

During the fall and spring, transect surveys were conducted throughout the day; however, in the summer, when temperatures were at their highest, transect surveys were conducted in the morning and late afternoon. In order to find lizards by direct observation in both burned and unburned areas, each transect line was walked two times and a snake stick used to flush lizards from grasses and shrubs. Sighting effort was concentrated to 5 m on either side of the transect line. Reptile species were identified, and distance along the transect line was documented in 5 m segments. During the course of this study I conducted a total of 1,542 transects (14 sites x 3 replicates x 36 times).

Pitfall Trapping

Pitfall arrays were established at the seven habitat patches to determine the diversity of reptile species in patches and monitor movements (Table 2). At each patch six 5-gallon plastic buckets were buried so the rims were flush with the soil surface. Three drainage holes were drilled into the bottom of all traps to prevent the accumulation of water. Each trap was fitted with a cover to provide shade and protection. The covers were inverted plastic bucket lids with three 5 by 5 cm tall pieces of wood attached at equal distances along the edge (Fisher et al., 2004). Attached to each cover was a 50 cm long piece of jute that served as a rodent escape string to minimize mortality. The pitfall traps were stocked with two to three small pieces of kibble, a 12 cm long by 5 cm diameter PVC pipe piece lined with small amounts of batting, and a 3-5 cm piece of wet sponge to keep trapped animals hydrated (Karraker, 2001; Persons and Nowak, 2006). When the wet sponge attracted ants it was temporarily removed (Fisher et al., 2004). When in use, traps were checked every 12 hours. When not in use, the bucket lid was securely fastened, rocks placed on the lid, and soil placed loosely over the lid to seal the trap.

Each bucket trap was separated by 7.5 m of 30 cm tall tan cloth drift fencing, which guided reptiles differentially into traps from burned and unburned habitats. Each array was arranged in a zigzag pattern, providing more intercept angles (Fisher et al., 2004). The buckets were completely fenced on three sides, with three buckets fenced on the patch side and three buckets fenced on the burn side (Figure 3). This design allowed for the study of directional movement, as individuals captured in buckets fenced on the patch side came from the burn area and individuals captured in buckets fenced on the burn side were moving away from the patch. The fencing was held in place by wooden stakes and buried 7-12 cm into the ground.

The array and trap numbers of all captured lizards were recorded. A small tissue sample was taken from the tail tip and preserved in 95% ethanol for possible later genetic

analysis (Hirsch et al., 2002). For easy recognition of an individual from a distance captured lizards were marked, based on their site location, with nail polish. Because they were captured in higher numbers, *Uta stansburiana* (side-blotched lizard) were also marked by toe clipping one digit (Ferner, 1979; Swingland, 1978). Small mammals (that did not escape via the escape string) and captured invertebrates were recorded to species and family, respectively. No mortalities occurred during the course of this study and all individuals were released at the site of capture.

Trapping was conducted on a monthly basis, between temperatures of 2-42°C. Traps were closed during heavy rains and when temperatures reached 0°C to prevent mortality. Trap effort for this study was defined as the number of open traps per trap session, with a session being 12 hours. Trap effort was 5,324 trap days/nights (7 arrays x 6 buckets in each array x 135 trap sessions-346 trap closures due to unforeseen circumstances).

Statistical Analysis

A Shapiro-Wilk test for normality was conducted, and when data were not normally distributed transformations using $\log(x)$, $\ln(x)$, x^2, and $\sqrt{x}$ were performed. Analyses involving herpetological community structure were conducted using PRIMER. All other analyses were completed using PRISM statistical software.

The mean, standard deviation, and minimum/maximum temperatures were calculated for temperature data. Air and ground surface temperatures in warm (May-August 2006 and 2007) and cold seasons (September-October 2006 and March-April 2007) were analyzed using paired *t*-tests.

Vegetation data were analyzed using χ^2, with the means and standard deviations of each plant height class calculated to compare plant heights in burned and unburned areas.

The observation rate of reptile species seen during transect surveys was calculated. ANOSIM (analysis of similarity) of species diversity between years and in burned and vegetated habitats and SIMPER (similarity percentages) analyses were conducted (Clarke, 1993). Transect data collected on *U. stansburiana* locations by line segment through time in each habitat type were analyzed using Friedman randomized block test, χ^2, and Fisher's Exact tests.

The capture rate of each lizard species caught during pitfall trapping was calculated along with the recapture rate for *U. stansburiana*. ANOSIM and SIMPER analyses were conducted to determine dominance in the herpetological community. Abundance data collected on trapped *U. stansburiana* were analyzed with a paired *t*-test and a Fisher's Exact test. Species of mammal and family of invertebrate captured were also tallied.

RESULTS

Ambient Air, Ground Surface, and Subterranean Temperatures

The mean ambient air temperature (±*SD*) for the 2006 and 2007 warm seasons combined was 31.1 ± 5.0ºC and for cold seasons was 20.6 ± 7.2ºC. Ambient air temperatures in the warm season of 2007 were significantly higher than 2006 ($t = 5.420$, $df = 195$, $p < 0.0001$, $\bar{x}$ 2006 = 29.6 ± 5.1, $\bar{x}$ 2007 = 32.4 ± 4.5). The means of the cold seasons were not significantly different ($t = 0.3196$, $df = 55$, $p = 0.7505$, $\bar{x}$ = 20.6 ± 7.2) from one another (Figure 4a).

Ground surface temperature data for 2006 and 2007 were divided by habitat type, season, and year creating data sets for 2006 and 2007 of warm season unburned, warm season burned, cold season unburned, and cold season burned. Unburned habitats were not found to be significantly different between years in the warm season ($t = 0.0206$, $df = 194$, $p = 0.9836$, $\bar{x}$ = 31.5 ± 5.9). Significant differences were found in the cold season ($t = 3.570$, $df = 55$, $p = 0.0007$, $\bar{x}$ 2006 = 19.3 ± 5.2, $\bar{x}$ 2007 = 16.7 ± 6.9), with 2006 being warmer. In burned habitat significant differences were not found between years in the warm season ($t = 1.091$, $df = 193$, $p = 0.2767$, $\bar{x}$ = 32.5 ± 6.1), while the 2006 cold season showed a significant difference in means between years ($t = 8.877$, $df = 52$, $p < 0.0001$, $\bar{x}$ 2006 = 19.5 ± 5.6, $\bar{x}$ 2007 = 17.5 ± 7.0). Also, burned habitats in the warm season had significantly higher temperatures ($t = 11.61$, $df = 415$, $p < 0.0001$, $\bar{x}$ unburned = 31.5 ± 5.9, $\bar{x}$ burned = 32.5 ± 6.0) than unburned. The cold season ($t = 0.6167$, $df = 112$, $p = 0.5387$, $\bar{x}$ = 18.2 ± 6.3) did not have significantly higher temperatures in burned habitats (Figure 4b).

Subterranean temperatures in the warm season of 2007 were significantly higher in both habitat types (unburned $t = 2.003$, $df = 195$, $p = 0.0466$, $\bar{x}$ 2006 = 30.6 ± 8.2, $\bar{x}$ 2007 = 31.2 ± 5.6, and burned $t = 2.239$, $df = 195$, $p = 0.0263$, $\bar{x}$ 2006 = 32.4 ± 8.3, $\bar{x}$ = 32.8 ± 5.4). I found that 2006 was significantly colder in the cold seasons in both habitats (unburned $t = 10.61$, $df = 55$, $p<0.0001$, $\bar{x}$ 2006 = 15.2 ± 4.5, $\bar{x}$ 2007 = 11.9 ± 6.4, and burned $t = 9.739$, $df = 55$, $p < 0.0001$, $\bar{x}$ 2006 = 15.7 ± 4.1, $\bar{x}$ 2007 = 12.6 ± 6.2). In the warm season subterranean temperatures in the burned area were significantly higher than in the unburned area ($t = 50.08$, $df = 417$, $p < 0.0001$, $\bar{x}$ unburned = 30.9 ± 6.9, $\bar{x}$ burned = 32.6 ± 6.9). Subterranean temperatures in burned habitats were also higher in the cold season ($t = 7.641$, $df = 111$, $p < 0.0001$, $\bar{x}$ unburned = 13.5 ± 5.5, $\bar{x}$ burned = 14.2 ± 5.1) during this study (Figure 4c).

During pitfall trapping the minimum air temperature recorded was 0ºC and the maximum temperature was 42ºC.

Vegetation Point-Intercept Transect Surveys

I found that only counts of plants <10 cm tall at one site in the burned area along the fire perimeter and one site in the burned area around a habitat patch, were normally

distributed. The total number of plants in the unburned areas (1,440; 68.58% total cover) was higher than in burned areas (846; 40.28% total cover). There were differences in the distribution of vegetation heights in each habitat ($\chi^2 = 389.9$, $df = 1$, $p < 0.0001$). There were significantly more plants in the burned area under 10 cm than in any other height class in either habitat (Table 3). The number of plants in burned areas in this height class increased from 2006-2007 (264 and 345 total plants). For all heights, except <10 cm, unburned habitats had more plants per site than burned. Although all plants seen were not recorded to species, of those recorded 2% and 21% were noted as *Erodium cicutarium* or a grass species in unburned areas. In burned areas this trend was reversed with *E. cicutarium* accounting for 31% and grasses making up only 7%.

Reptile Transect Surveys

During transect surveys five lizard and one snake species were observed (Table 4). Multi dimensional scaling (MDS) showed that transect sites clustered together by habitat type with the exception of two sites; one unburned patch and one burned perimeter transect location. These two sites were removed from the analysis because they had significantly more zero values and were outliers that made it impossible to determine how locations clustered. I found no significant differences in the species assemblages between years (ANOSIM, $R = 0.018$, $p = 0.271$ and $R = -0.043$, $p = 0.888$) or between unburned and burned habitats ($R = 0.053$, $p = 0.109$ and $R = 0.010$, $p = 0.333$) along the perimeter and in the patch locations, respectively. Therefore, data from 2006 and 2007 were combined and reanalyzed using ANOSIM. Species found at perimeter and patch sites did not differ significantly ($R = 0.038$, $p = 0.272$); however, differences were found ($R = 0.220$, $p = 0.022$) between unburned and burned locations. A SIMPER analysis showed that in the unburned areas, *U. stansburiana* accounted for 88.0% of individuals, with *A. tigris* and *S. occidentalis* making up 14.7% and 13.5% of individuals, respectively. In the burned areas *U. stansburiana* comprised 98.6% of individuals.

U. stansburiana abundance data were not normally distributed and a normalizing transformation could not be found. A Friedman randomized block test found no significant differences in the number of individuals seen by segment location along transects in each habitat type through time (Friedman statistic = 6.500, $p = 0.0897$). Differences were found between habitat types ($\chi^2 = 9.952$, $df = 3$, $p = 0.0190$). Burned areas around patches in 2006 and outside the perimeter in 2007 had the fewest individuals. Most *U. stansburiana* were recorded in burned areas along perimeter sites in 2006, followed by unburned patch sites in 2007 (Figure 5). Although combining perimeter and patch sites yielded more individuals found in unburned habitat ($n = 77$ compared to $n = 62$), there were no significant differences in the number of *U. stansburiana* in unburned and burned habitats (Fisher's Exact test; $p = 0.0624$). Also, no detectable differences were found when year data were combined (Fisher's Exact test; $p = 0.1201$), although burned patches had the fewest ($n = 22$), while burned perimeter and unburned patch habitats had the most individuals (both had $n = 39$). Surprisingly, significant differences were found when unburned and burned sites along the perimeter and at patch locations were combined (Fisher's Exact test; $p = 0.0258$).

Pitfall Trapping

During pitfall trapping six lizard species were captured (Table 5). MDS showed that pitfall trap sites clustered together by year with the exception of one site in a patch location in 2006, which had more zero data points than other sites. This site was removed in order to see patterns in the remaining data. Species abundance did differ significantly between years (ANOSIM, $R = 0.216$, $p = 0.044$). More individuals were captured in 2007 ($n = 60$) than 2006 ($n = 36$). Also, 2006 had one single species not captured in 2007, while 2007 had two that were not present in 2006. *U. stansburiana* dominated the herpetofaunal assemblages in both years; however, this species was represented in a higher percentage in the 2007 (SIMPER, 2006 = 92.6% and 2007 = 98.2%).

Of the 80 *U. stansburiana* captured over the course of this study, 19 were recaptures, resulting in a recapture rate of 23.75%. In 2006 there were very few recaptures (10.71%); however, 2007 saw an increase in recaptured individuals (30.77%). Recaptures of individuals were removed from statistical analyses. The total number of *U. stansburiana* captured by site were normally distributed in both years (2006 $p = 0.2601$ and 2007 $p = 0.7222$). No significant differences in the number of individuals caught between years ($t = 1.135$, $df = 12$, $p = 0.2787$) was found. No significant differences in the direction of movement of individuals was found when these data were combined for analysis (Fisher's Exact test; $df = 4$, $p = 0.2968$), even though the number of *U. stansburiana* moving into patches actually doubled (9 to 18) from 2006-2007 (Figure 6). During trapping more juveniles were captured (66%) than adults (34%), with most *U. stansburiana* being captured in 2007.

I also recorded the numbers of mammals and invertebrates captured in pitfall traps. As these individuals could easily climb the drift fencing their direction of movement could not be determined. Interestingly, the number of mammalian species captured decreased, as did the total number of individuals captured from the first to the second year (Table 6). Conversely, the number of invertebrate families and the total number of individuals captured increased from 2006-2007 (Table 7).

DISCUSSION

Temperature and Vegetation

Due to air temperature variation, 2007 was warmer than 2006, but both ground surface and subterranean temperatures were higher in burned areas than in unburned areas in both years.

The plant community in unburned areas had almost 30% more cover than burned areas and remained relatively stable through time. However, the burned areas had more than twice the number of plants in the <10 cm height class, and very few grew to over 10 cm during the course of this study. This indicates that most were low growing ground cover species. This is consistent with long term studies of plant communities in the Southwest that have found areas affected by wildfire are rapidly colonized by low growing ground cover species that are predominantly alien (Brooks, 2002; Brooks and Matchett, 2003). Additionally, soil nutrient research in the Mojave found that grasses were better competitors and often become dominant following disturbance (Brooks, 1999).

Comparison of Transect and Pitfall Data

Transect and pitfall surveys had comparable species diversity with each other. *Uta stansburiana* was the dominant species in all locations. I found the highest number along the fire perimeter on the burned side in 2006, which is similar to a study conducted after a wildfire in Arizona that found reptiles exhibited a preference for disturbed sites (Cunningham et al., 2002). However, in 2007 the number of individuals found in this area decreased by more than half. It may be that individuals utilized this area more heavily initially because the higher ground temperatures allowed for optimal basking sites. In 2007 temperatures may have become too high creating a less than ideal habitat type that did not provide a thermoregulatory gradient or enough cover (Wilson, 1991). The number of *U. stansburiana* in unburned perimeter locations was relatively constant through time, indicating that this population was the most stable. The numbers found at patches increased in burned and unburned areas, with unburned sites having more individuals.

The directional design of the pitfall arrays allowed me to assess whether individuals were moving into or out of habitat patches. However, no directional pattern was detected, likely because of the low numbers of individuals captured. However, in 2006 the number of *U. stansburiana* captured in pitfall traps at patch sites ($n = 28$) was comparable to the number seen during transect surveys at the same locations ($n = 25$). In 2007 more were captured ($n = 52$) than seen ($n = 37$). It may be that the increased temperatures in 2007 altered the movements of *U. stansburiana*, decreasing their daily activity.

Future Research Recommendations

This research would have benefited from a longer study period. Two years is not a sufficient amount of time to accurately determine trends in a fragmented system that is

undergoing post-wildfire successional stages. Many environmental parameters, including yearly temperature and rainfall fluctuations, could account for the trends seen and result in notable year-to-year variability (Hirsch et al., 2002).

Conservation Implications

Although the results of a study conducted in a single location and affected by a single event may not be fully extrapolated to other locations or events, it is clear that wildfire is a serious threat to biodiversity in the Mojave. The effects of large desert fires are poorly understood, largely because this is a relatively new problem (Brooks, 2002; Brooks and Matchett, 2003). Information on floral community succession and faunal survival is useful to help understand the long-term consequences of altering landscapes, and could lead to increased control of invasive species. These species have created a positive feedback system, or a grass-fire cycle, in the Mojave. The resulting habitats are increasingly homogeneous, and provide few resources (Esque, 1999; Esque et al., 2003; Valentine et al., 2007).

The presence of *U. stansburiana* is a good indicator of the possible establishment of healthy populations of many other species. *U. stansburiana* is an abundant and widespread lizard that is a food source for many species that cannot reoccupy an area until suitable numbers of prey are present (Stebbins, 2003). Low numbers will negatively impact the community, decreasing both diversity and abundance. This study suggests that wildfire in the Mojave negatively affects the reptile community.

Due to the hostile conditions and already limited resources, desert environments are not able to maintain dense populations of wildlife, creating fragile systems composed of highly specialized species. Deserts, although coming under increasing pressure from human expansion and activities, are some of the most inhospitable and therefore remote and unexploited areas in the continental United States. Wildlands are becoming increasingly rare worldwide and few ecosystems contain organisms with such unique adaptations to extreme conditions as desert regions, making conservation in these areas a critical concern.

TABLE 1. Transect Locationss in the Hackberry Region, Mojave National Preserve

Site	Starting Easting	Starting Northing	Ending Easting	Ending Northing	Elevation (m)
Patch 1	645412	3892561	645405	3892517	1596
	645409	3892565	645438	3892531	
	645431	3892589	645438	3892543	
Patch 2	645425	3892203	645476	3892204	1591
	645422	3892195	645470	3892178	
	645438	3892181	645467	3892157	
Patch 3	642829	3887189	642812	3887237	1661
	642821	3887185	642789	3887221	
	642806	3887173	642777	3887208	
Patch 4	642810	3887316	642814	3887365	1665
	642786	3887307	642798	3887350	
	642754	3887298	642787	3887342	
Patch 5	642814	3887533	642841	3887575	1670
	642788	3887525	642821	3887566	
	642708	3887531	642806	3887571	
Patch 6	645913	3887650	642933	3887695	1684
	642929	3887649	642944	3887699	
	642954	3887662	642962	3887709	
Patch 7	643023	3887958	643039	3887909	1679
	643050	3887969	643049	3887917	
	643077	3887972	643063	3887927	
Perimeter 1	646600	3892811	646555	3892819	1594
	646598	3892786	646549	3892794	
	646586	3892763	646540	3892786	
Perimeter 2	646545	3892659	646493	3892658	1604
	646552	3892636	646500	3892638	
	646536	3892610	646488	3892620	
Perimeter 3	646524	3892565	646480	3892567	1656
	646522	3892553	646480	3892546	
	646538	3892529	646492	3892526	
Perimeter 4	646513	3892468	646465	3892474	1660
	646506	389245	646457	3892448	
	646498	3892431	646458	3892678	
Perimeter 5	646586	3892634	646587	3892681	1580
	646595	3892616	646611	3892668	
	646623	3892625	646623	3892678	
Perimeter 6	645283	3892595	645259	3893556	1582
	645262	3892604	645247	3893560	
	645244	3892615	645237	3893568	
Perimeter 7	645167	3893604	645186	3893568	1580
	645153	3893610	645175	3893571	
	645132	3893600	645150	3893554	

Note: All locations in map datum NAD83, UTM zone 11.

TABLE 2. Locations of Pitfall Trap Arrays in the Hackberry Region of the Mojave National Preserve

Array	Easting	Northing	Elevation (m)
1	645395	3892528	1596
2	645456	3892203	1591
3	642811	3887222	1661
4	642804	3887343	1665
5	642873	3887558	1670
6	642942	3887683	1684
7	643035	3887924	1679

Note: All locations in map datum NAD83, UTM zone 11.

TABLE 3. Percent Vegetation Cover in Unburned and Burned habitats by Height Class

Height Class (cm)	Unburned		Burned	
	Number	Percent Cover	Number	Percent Cover
<10	220	10.48	631	30.05
10-30	295	14.05	133	6.33
30-50	248	11.81	63	3.00
50-100	345	16.43	16	0.76
>100	332	15.81	3	0.14
Total	1440	68.58	846	40.28

TABLE 4. Reptile Species Observed During Transect Surveys

Species	2006		2007		Unburned		Burned	
	Number	Rate	Number	Rate	Number	Rate	Number	Rate
Aspidocelus tigris Western whiptail	7	0.3684	4	0.2105	11	0.2895	0	0
Gambelia wislizenii Long-nosed leopard lizard	2	0.1053	0	0	1	0.0263	1	0.0263
Masticophis taeniatus Striped whipsnake	1	0.0526	0	0	0	0	1	0.0263
Phrynosoma platyrhinos Desert horned lizard	0	0	1	0.0526	0	0	1	0.0263
Sceloporus occidentalis Western fence lizard	8	0.4211	7	0.3684	5	0.1316	10	0.2632
Uta stansburiana Side-blotched lizard	80	4.2105	56	2.9474	75	1.9737	61	1.6053
Total	98	5.1579	68	3.5789	92	2.4211	74	1.7105

Note: Observation rates were calculated using number of observations/number of transects conducted (Persons and Nowak, 2006).

TABLE 5. Reptile Species Captured During Pitfall Trapping

Species	2006		2007	
	Number	Capture Rate	Number	Capture Rate
Aspidocelus tigris Western whiptail	5	0.0725	1	0.0145
Gambelia wislizenii Long-nosed leopard lizard	1	0.0145	0	0
Sceloporus magister Desert spiny lizard	0	0	3	0.0435
Sceloporus occidentalis Western fence lizard	2	0.0290	5	0.0435
Uta stansburiana Side-blotched lizard	28	0.4056	52	0.7536
Xantusia vigilis Desert night lizard	0	0	1	0.0145
Total	36	0.5216	62	0.8969

Note: Capture rates were calculated using number of captures/number of pitfall trap sessions conducted (Persons and Nowak, 2006).

TABLE 6. Mammal Species Captured During Pitfall Trapping

Species	2006	2007
Dipodomys deserti Desert kangaroo rat	6	3
Lagurus curtatus Sagebrush vole	3	0
Perognathus longimembris Little pocket mouse	1	1
Perognathus penicillatus Desert pocket mouse	0	1
Peromyscus sp. Pygmy mouse species	3	0
Thomomys bottae Valley pocket gopher	1	1
Total Number of Individuals	14	6
Total Number of Species	5	4

TABLE 7. Invertebrate Families Captured During Pitfall Trapping

Family	2006	2007
Caraboctonidae (Desert scorpions)	35	71
Cerambycidae (Long-horned beetles)	0	1
Cicadidae (Cicadas)	0	1
Eremobatidae (Windscorpions)	31	35
Gryllacrididae (Camel crickets)	98	152
Gryllidae (Crickets)	3	0
Mantidae (Mantids)	1	1
Mutillidae (Velvet ants)	0	2
Myrmeleontidae (Antlions)	0	1
Pompilidae (Tarantula hawks)	0	1
Reduviidae (Assassin bugs)	0	13
Scolopendridae (Multicolored centipedes)	2	0
Tenebrionidae (Darkling beetles)	483	623
Theraphosidae (Blonde tarantulas)	0	1
Total Number of Individuals	653	902
Total Number of Families	7	12

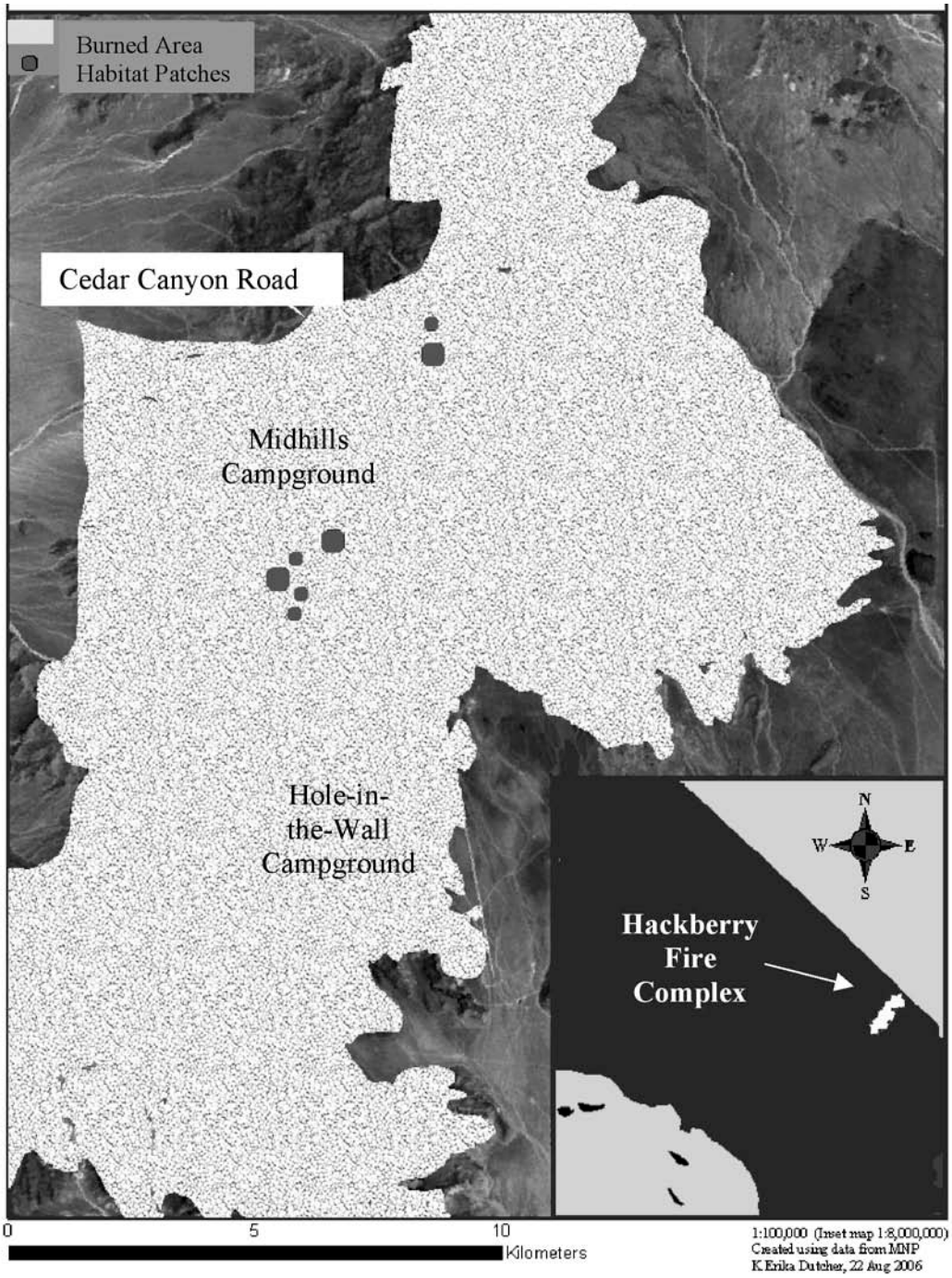

FIGURE 1. Habitat patch locations within the Hackberry region of the Mojave National Preserve. Habitat patch size not to scale. The subset map shows the location of the Hackberry wildfire in Southern California. Map created by K. Erika Dutcher and Dr. D. Underwood using data from the National Park Service, 2006.

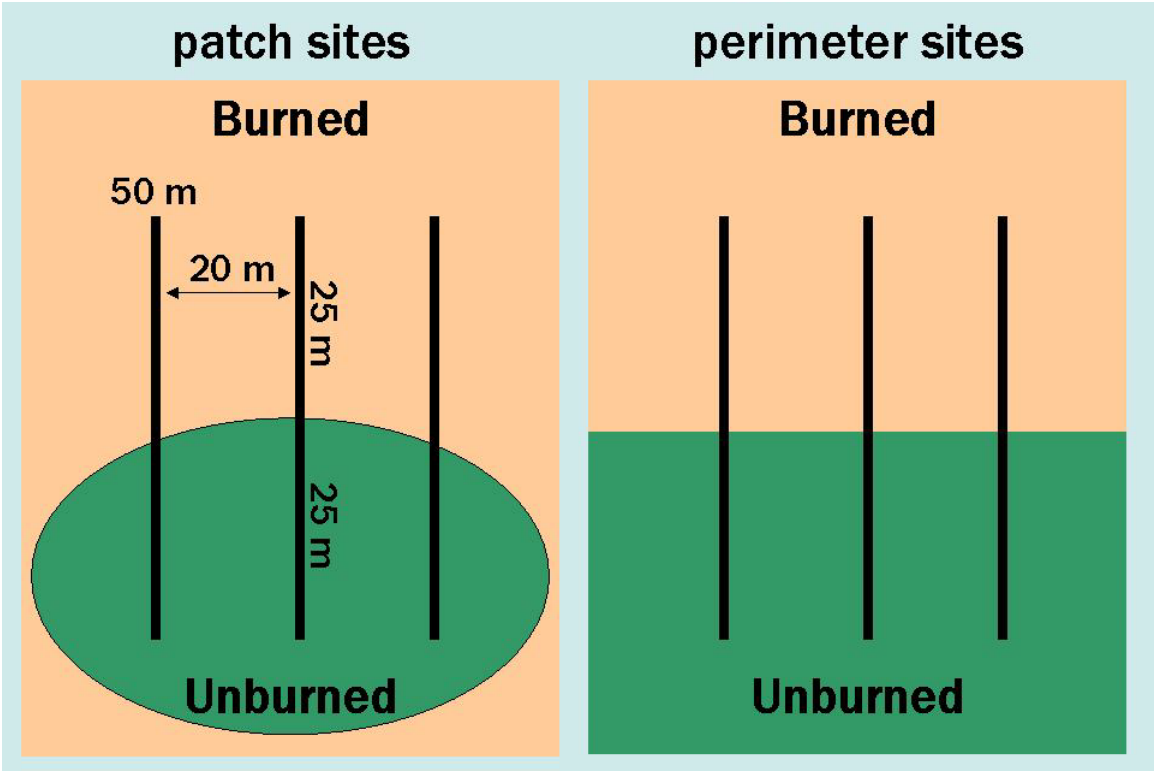

FIGURE 2. Transect design. Each site had three 50 m transects separated by 20 m. Half (25 m) of each transect was located in burned habitat and 25 m in unburned habitat.

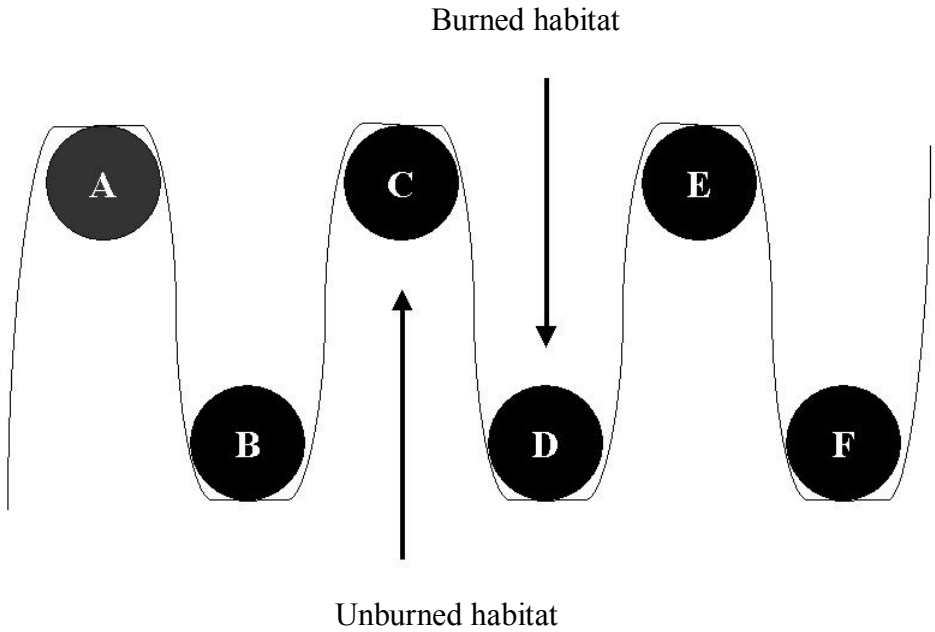

FIGURE 3. Pitfall array design. Buckets were fenced on three sides to prevent reptiles from the burned area entering traps A, C, and E and reptiles from the unburned area entering traps B, D, and F.

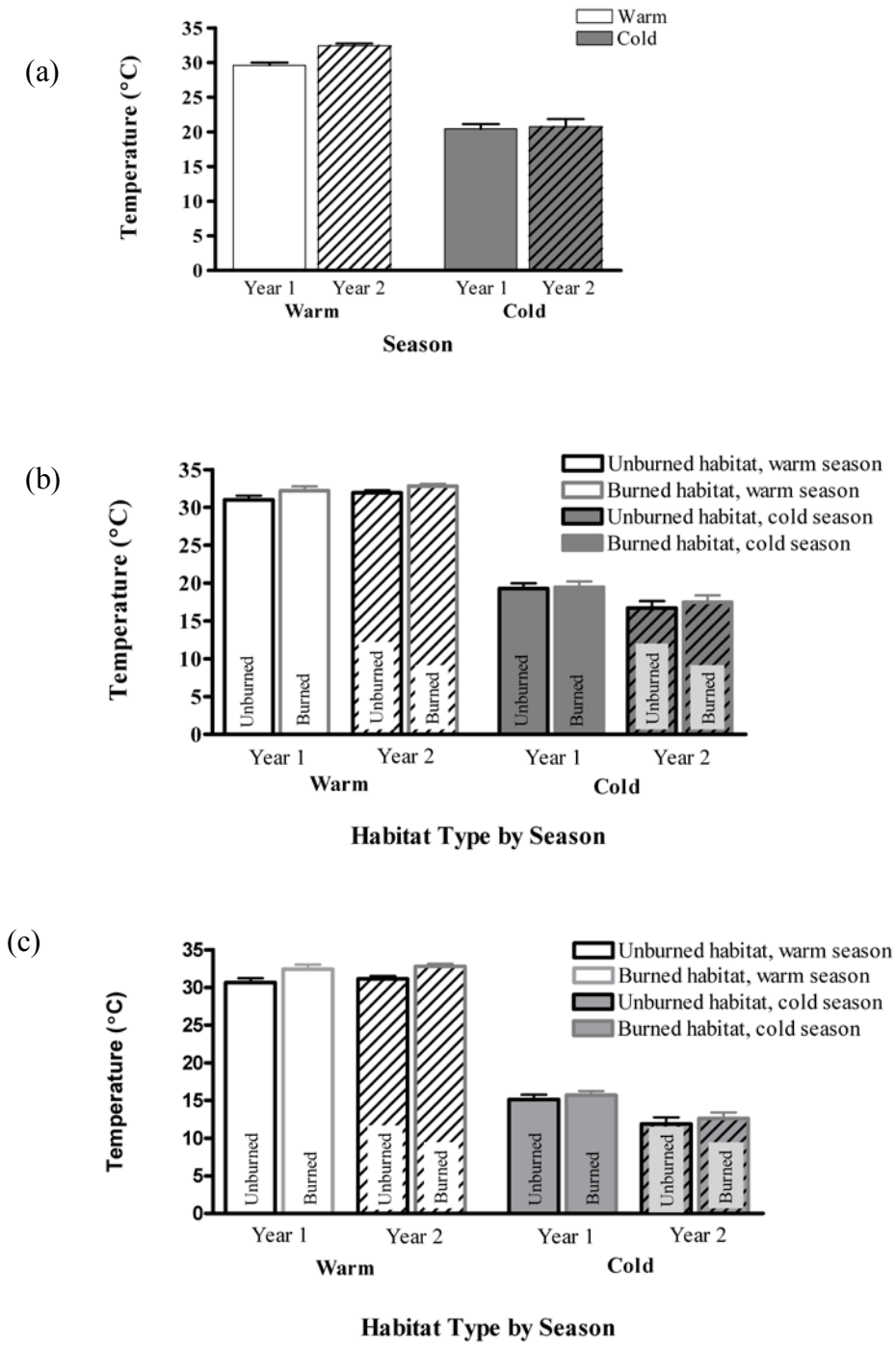

FIGURE 4. Ambient, ground, and subterranean temperatures ($\bar{x} \pm$ SD). (a) Average ambient temperatures by year in the warm and cold seasons. (b) Average ground temperatures for unburned and burned habitats by year in each season. (c) Average subterranean temperatures for both habitats by year in each season.

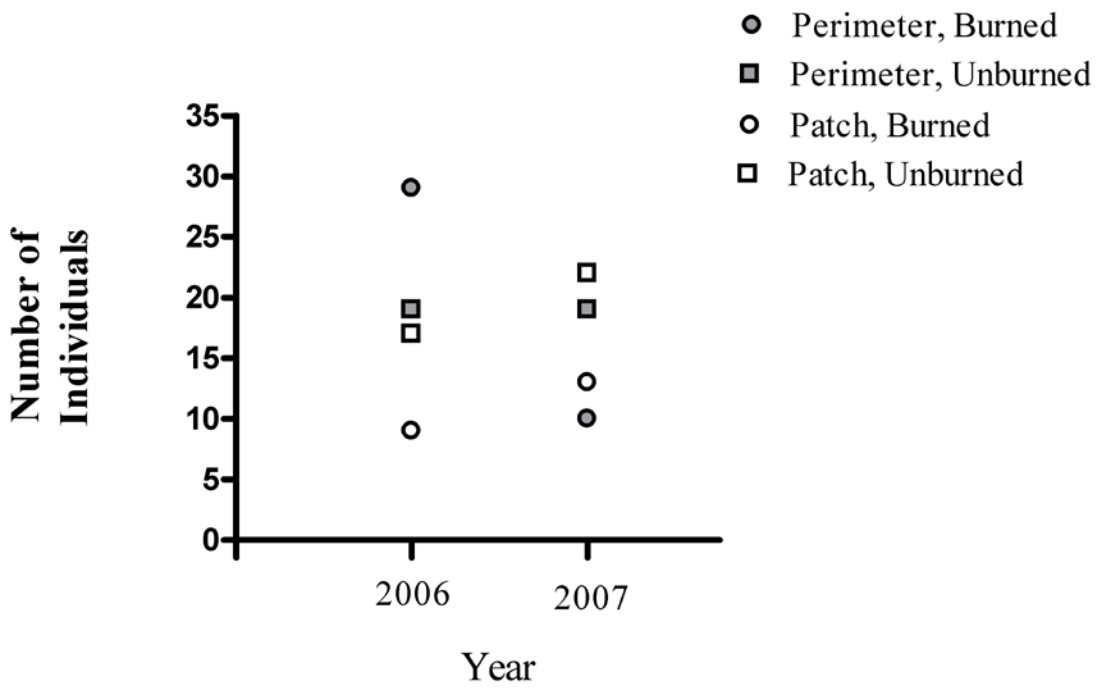

FIGURE 5. Total number of *Uta stansburiana* observed during transect surveys in each habitat type by year.

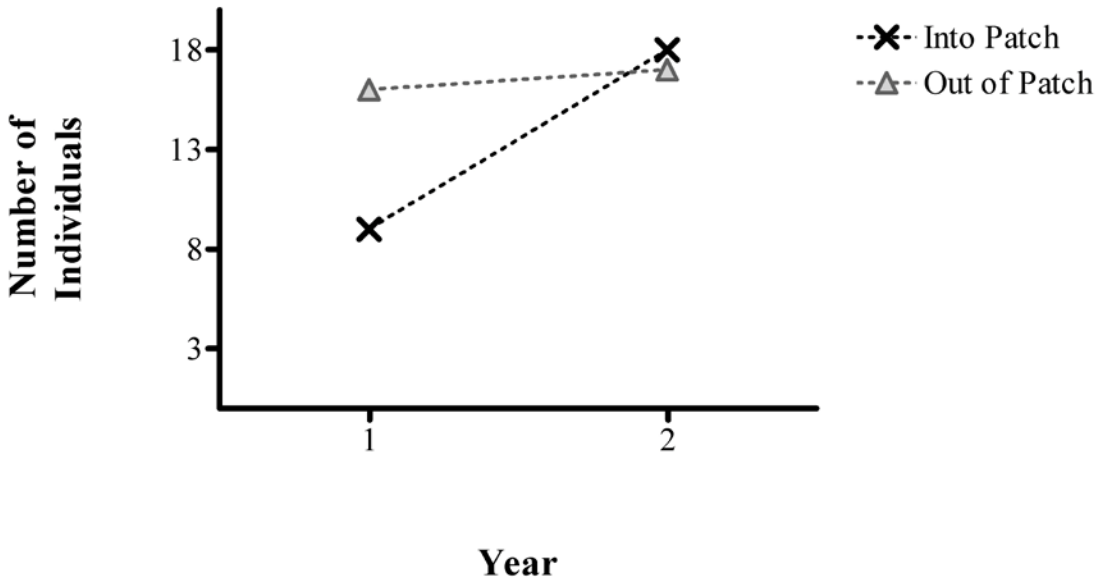

FIGURE 6. Total number of *Uta stansburiana* captured in pitfall traps moving into or out of habitat patches by year. Recaptured individuals were removed from the totals.

LITERATURE CITED

Attum O, Eason P, Cobbs G, Baha El Din SM. 2006. Response of a Desert Lizard Community to Habitat Degradation: Do Ideas About Habitat Specialists/Generalists Hold? Biological Conservation 133: 52-62.

Barbour MG, Burk JH, Pitts WD, Gilliam FS, Schwartz MW. 1999. Terrestrial Plant Ecology. 3RD Edition. Menlo Park, California: Benjamin Cummings Press. 239pp.

Brooks ML. 1999. Habitat Invasibility and Dominance by Alien Annual Plants in the Western Mojave Desert. Biological Invasions 1:325-337.

Brooks ML. 2000a. *Bromus madritensis* spp. *rubens*. In: Bossard CC, Randall JM, and Hoshovsky MC, editors. Invasive Plants of California's Wildlands. University of California Press, Ltd., London. P. 72-76.

Brooks ML. 2000b. *Schismus arabicus, Schismus barbatus*. In: Bossard CC, Randall JM, and Hoshovsky MC, editors. Invasive Plants of California's Wildlands. University of California Press, Ltd., London. P. 287-291.

Brooks ML. 2002. Peak Fire Temperatures and Effects on Annual Plants in the Mojave Desert. Ecological Applications 12:1088-1102.

Brooks ML, Matchett JR. 2003. Plant Community Patterns in Unburned and Burned Blackbrush (*Coleogyne ramosissima torr.*) Shrublands in the Mojave Desert. Western North American Naturalist 63:283-298.

Clarke K. 1993. Nonparametric Multivariate Analyses of Changes in Community Structure. Australian Journal of Ecology 18:117-143.

Cunningham SC, Babb RD, Jones TR, Taubert BD, and Vega R. 2002. Reaction of Lizard Populations to a Catastrophic Wildfire in a Central Arizona Mountain Range. Biological Conservation 107:193-201.

.

Davies KF, Gascon C, Margules CR. 2001. Habitat Fragmentation: Consequences, Management, and Future Research Priorities. In: Soule ME, and Orians GH, editors. Conservation Biology: Research Priorities for the Next Decade. Society for Conservation Biology, Island Press, Washington. P. 81-98.

Esque TC. 1999. Managing Fire and Invasive Plants in the Mojave Desert: Defining an Integrated Research Program to Address Knowledge Gaps. Proceedings from the Mojave Desert Science Symposium February 25-27. P. 18-20.

Esque TC, Schwalbe CR, DeFalco LA, Duncan RB, Hughes TJ. 2003. Effects of Desert Wildfires on Desert Tortoise (*Gopherus agasizii*) and Other Small Vertebrates. The Southwestern Naturalist 18:103-110.

Fahrig L. 2003. Effects of Habitat Fragmentation on Biodiversity. The Annual Review of Ecology, Evolution, and Systematics 34:487-515.

Faria AS, Lima AP, Magnusson WE. 2004. The Effects of Fire on Behavior and Relative Abundance of Three Lizard Species in an Amazonian Savanna. Journal of Tropical Ecology 20:591-594.

Ferner JW. 1979. A Review of Marking Techniques for Amphibians and Reptiles. Society for the Study of Reptiles and Amphibians, Herpetological Circular No. 9, Ohio. 42pp.

Fisher R, Stokes D, Rochester C, Hathaway S, Brehme C, Case T. 2004. Reptile Biodiversity: Standard Methods for Inventory and Monitoring. UC San Diego, Department of Biology for the USGS: USGS Technical Report. 56pp.

Friend GR. 1993. Impact of Fire on Small Vertebrates in Malle Woodlands and Heathlands of Temperate Australia: a Review. Biological Conservation 65(2):99-114.

Hanes TL. 1971. Succession After Fire in the Chaparral of Southern California. Ecological Monographs 41(1):27-52.

Hirsh R, Hathaway S, Fisher R. 2002. Herpetofauna and Small Mammal Surveys on the Marine Corps Air Ground Combat Center, Twentynine Palms, CA March 1999-October 2001. USGS Project End Report. Prepared by the Western Ecological Research Center for the Marine Corps Air Ground Combat Center. 20pp.

http:// www.nps.gov/moja/parkmgmt/upload/Hackberry_BAER_Plan%2006-05.pdf. (Last Modified 05 July 2005; Retrieved 04 December 2005; National Park Service, Hackberry_BAER_Plan.pdf.

Karraker NE. 2001. String Theory: Reducing Mortality of Mammals in Pitfall Traps. Wildlife Society Bulletin 29(4):1158-1162.

McKenzie D, Gedalof Z, Peterson D, Mote P. 2004. Climactic Change, Wildfire, and Conservation. Conservation Biology 18:890-902.

Mojave National Preserve Maps. 2005. Hackberry Complex Fire Maps. Scale given at 1:50,000; generated by Dingman, Sandy. "GIS Files for Hackberry Fires and Mojave National Preserve".

Morris DW. 1995. Habitat Selection in Mosaic Landscapes. In: Hansson L, Fahrig L, and Merriam G editors. Mosaic Landscapes and Ecological Processes. London: Chapman and Hall. P. 111-135.

National Park Service. 2003. Long-Range Interpretive Plan: Mojave National Preserve. Barstow, California: Mojave National Preserve. 79pp.

Odion DC, Davis FW. 2000. Fire, Soil Heating, and the Formation of Vegetation Patterns in Chaparral. Ecological Monographs 70(1):149-169.

Parr CL, Chown SL. 2003. Burning Issues for Conservation: A Critique of Faunal Fire Research in Southern Africa. Austral Ecology 28:384-395.

Patten DT, Smith EM. 1975. Heat Flux and the Thermal Regime of Desert Plants. In: Hadley NF, editor. Environmental Physiology of Desert Organisms. Academic Press, Pennsylvania. P. 1-19.

Persons TB, Nowak EM. 2006. Inventory of Amphibians and Reptiles at Death Valley National Park. U.S. Department of the Interior, U.S.G.S. 32pp.

Reice SR. 2001. The Silver Lining: The Benefits of Natural Disasters. Princeton University Press, Princeton. 218pp.

Russell KR, Van Lear DH, Guynn DC Jr. 1999. Prescribed Fire Effects on Herpetofauna: Review and Management Implications. Wildlife Society Bulletin 27(2):374-384.

Setser K, Cavitt JF. 2003. Effects of Burning on Snakes in Kansas, USA, Tallgrass Prairie. Natural Areas Journal 23:315-319.

Stebbins RC. 2003. A Field Guide to Western Reptiles and Amphibians. 3RD Edition. New York: Houghton Mifflin Co. 533pp.

Swingland IR. 1978. Marking Reptiles. In: Stonehouse B, editor. Animal Marking: Recognition Marking of Animals in Research. University Park Press, Baltimore. P. 119-132.

Taylor JE, Fox BJ. 2001. Disturbance Effects from Fire and Mining Produce Different Lizard Communities in Eastern Australian Forests. Austral Ecology 26:193-204.

Turner MG, Romme WH, Gardner RH, Hargrove WH. 1997. Effects of Fire Size and Pattern on Early Succession in Yellowstone National Park. Ecological Monographs 67(4):411-433.

Valentine LE, Roberts B, Schwarzkopf L. 2007. Mechanisms Driving Avoidance of Non-Native Plants by Lizards. Journal of Applied Ecology 44:228-237.

Wilson BS. 1991. Latitudinal Variation in Activity Season Mortality Rates of the Lizard *Uta stansburiana*. Ecological Monographs 6(14):393-414.

Young J. 2000. *Bromus tectorum*. In: Bossard CC, Randall JM, and Hoshovsky MC, editors. Invasive Plants of California's Wildlands. University of California Press, Ltd., London. P. 76-77.