CALIFORNIA
ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Learning From Real-World Experience to Understand Renewable Energy Impacts to Wildlife

Gavin Newsom, Governor

March 2020 | CEC-500-2020-012

PREPARED BY:

Primary Author:
Tara J. Conkling
Hannah B. Vander Zanden
Sharon A. Poessel
Scott R. Loss
Taber D. Allison
Jay E. Diffendorfer
Adam E. Duerr
David M. Nelson
Julie Yee
Todd E. Katzner

U.S. Geological Survey
970 S. Lusk St.
Boise, ID 83706
208-426-5232
https://www.usgs.gov

Contract Number: EPC-14-061

PREPARED FOR:
California Energy Commission

David Stoms, Ph.D.
Project Manager

Jonah Steinbuck, Ph.D.
Office Manager
ENERGY GENERATION RESEARCH OFFICE

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

ACKNOWLEDGEMENTS

Funding for this work was provided by the California Energy Commission, grant EPC-14-061, and the U.S. Bureau of Land Management. The authors thank Maureen Thompson, Ryan Butryn, Heather Beeler, Thomas Dietsch, Tracy Borneman, Robert Doster, Haley Edwards Olson, Esther Wrightman, and others who provided facility reports and other data. Stephen Lewis, Carol McIntyre, and Travis Booms provided golden eagle samples from Alaska, and Krysta Rogers provided golden eagle samples from California. The U.S. Fish and Wildlife Service assisted in providing specimens from Ivanpah Solar Electric Generating System, Renee Culver provided samples from Altamont Pass Wind Resource Area, Patricia Ortiz and Diane Schmidt obtained feathers from the carcasses, and Robin Paulman assisted with the isotope analysis. Michael Wunder contributed to the publication that resulted from Chapter 4. This project also benefitted from feedback from a technical advisory committee composed of members from state and federal agencies, for-profit and nonprofit corporate entities, and members of the research community. The members involved were: Amy Fesnock (U.S. Bureau of Land Management), Bronwyn Hogan (U.S. Fish and Wildlife Service), Garry George (Audubon California), Jeff Kelly (Oklahoma University), Kevin Martin (Terra Gen), Laura Nagy (Iberdrola), Magdalena Rodriguez (California Department of Fish and Wildlife), and Manuela Huso (U.S. Geological Survey). Technical advisory committee members and others listed here contributed as informal or formal peer reviewers for the work products generated in this study. Golden eagle samples were collected under the following permits: Alaska Department of Fish and Game Bird Banding Permits #22395 and #21678, U.S. Fish and Wildlife Service IACUC permit #2013-004, and U.S. Federal Bird Banding and Marking Permit #MB03368B. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the United States government. This report has been peer reviewed and approved for publication consistent with U.S. Geological Survey Fundamental Science Practices (https://pubs.usgs.gov/circ/1367/).

PREFACE

The California Energy Commission's Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution, and transportation.

In 2012, the California Public Utilities Commission established the Electric Program Investment Charge (EPIC) to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The California Energy Commission and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Learning From Real-World Experience to Understand Renewable Energy Impacts to Wildlife is the final report for the project Learning from Real-World Experience to Understand Renewable Energy Impacts to Wildlife (Grant Number EPC-14-061) conducted by the U.S. Geological Survey. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's research website (www.energy.ca.gov/research/) or contact the Energy Commission at 916-327-1551.

ABSTRACT

The project team sought to use real-world data to understand adverse effects to wildlife of renewable energy production that is critical to meeting California's climate and clean energy goals. The project had three main components. First, a systematic literature review studied 20 peer-reviewed publications and 612 reports from other nonreviewed sources from 231 wind and solar facilities in North America. Within California, 50 percent of facilities collected pre- and post-construction data, 30 percent had experimental study designs, and fewer than 7 percent estimated detection probability during habitat use surveys. Mitigation at wind power plants focused on repowering to reduce risk to soaring birds and at solar facilities emphasized wildlife deterrence and compensatory mitigation. Second, the authors developed a best-practices approach to employ environmental isotopes (for example, hydrogen obtained from animal tissue) and rescaling functions (a statistical approach to modeling the relationship between variables) to assign individual birds or bats to their place of origin. The team applied this approach to feathers from 411 individuals of 12 species killed at wind facilities and 515 individuals of 19 species killed at solar facilities. From 24 percent to 100 percent (mean ± SD = 49 percent ± 33 percent) and 25 percent to 100 percent (73 percent ± 25 percent) of birds grew feathers at a location outside the collection site at wind and solar facilities, respectively. Third, the authors constructed Bayesian integrated population models (probability models) for 29 focal species affected by wind or solar energy generation in California. Species predominantly local in origin generally had lower population growth rates than did species that were predominantly nonlocal in origin. These patterns illustrate the complex linkages between behavioral ecology, vulnerability to mortality, and population-level impacts to wildlife from fatalities at renewable energy facilities. This project benefits the renewable energy sector by providing a framework and specific tools for understanding environmental impacts of renewable energy generation.

Keywords: California, conservation, isoscape, mitigation, renewable energy, solar energy, stable isotopes, wildlife monitoring, wind energy

Please use the following citation for this report:

Conkling, Tara J., Hannah B. Vander Zanden, Sharon A. Poessel, Scott R. Loss, Taber D. Allison, Jay E. Diffendorfer, Adam E. Duerr, David M. Nelson, Julie Yee, and Todd E. Katzner. 2020. *Learning From Real-World Experience to Understand Renewable Energy Impacts to Wildlife*. California Energy Commission. Publication Number: CEC-500-2020-012.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS ... i

PREFACE ... ii

ABSTRACT ... iii

TABLE OF CONTENTS ... iv

LIST OF FIGURES ... vii

LIST OF TABLES ... viii

EXECUTIVE SUMMARY ... 1

- Background ... 1
- Project Purpose ... 1
- Project Approach ... 2
- Project Results ... 3
- Knowledge Transfer ... 4
- Benefits to California ... 4

CHAPTER 1: Introduction ... 5

- The Approach ... 7

CHAPTER 2: Assessing Standardization in Californian Studies of Renewable Energy Impacts on Wildlife ... 9

- Introduction ... 9
- Methods ... 10
  - Literature Search ... 10
  - Data Organization ... 11
  - Naming Conventions ... 12
  - Data Analysis ... 12
- Results ... 12
  - Frequency of Pre- and Post-Construction Surveys and How Survey Methodologies Have Evolved Over Time ... 12
  - Frequency of Experimental Design Elements in Surveys ... 17
  - Degree of Data Standardization Across Pre- and Post-Construction Surveys and Among Facilities ... 18

Discussion 21
Frequency of Pre- and Post-Construction Surveys 22
Frequency of Experimental Design Elements in Surveys 22
Degree of Data Standardization Across Pre- and Post-Construction Surveys and Among Facilities 22
Limitations and Recommendations for Increased Data Availability 23
Improving Monitoring at Renewable Energy Facilities 23
CHAPTER 3: Mitigation Practices at Renewable Energy Facilities in California and North America 25
Introduction 25
Methods 26
Literature Search 26
Data Organization and Analyses 26
Results 26
Discussion 31
Addressing Data Limitations 32
CHAPTER 4: Application of Isoscapes to Determine Geographic Origin of Terrestrial Wildlife for Conservation and Management in California 34
Introduction to Using Isoscapes to Infer Geographic Origin 34
Applications to Animal Ecology and Conservation Questions 35
Study Considerations 35
Data Sources 35
Tissue Type 37
Conducting Geographic Assignments with a Probabilistic Approach 38
Baseline Isoscape 39
Rescaling Function 40
Variance Model 40
Calculation of Conditional Probabilities 40
Post-Processing 41
Cautions 42
Example Application 42
Assignment Methods to Determine Geographic Origin 43
Interpreting Example Assignment Results 44

How Far Away Did Individuals Originate? 45
Recommendations and Future Horizons 47
CHAPTER 5: Geographic Origin of Avian Fatalities at Renewable Energy Facilities in California 48
Introduction 48
Methods 48
Sample Collection 48
Sample Analysis 52
Geographic Assignment Process 52
Results 58
Discussion 65
CHAPTER 6: Demography of Wildlife Species Affected by Renewable Energy Facilities in California 68
Introduction 68
Methods 68
Modeling Framework 71
Stable Isotopes to Determine Geographic Origin of Individuals Killed at Renewable Energy Facilities 71
Results 73
Discussion 79
Interpreting Demographic Models 79
Limitations to the Modeling Approach 81
Conclusions 81
CHAPTER 7: Technology/Knowledge Transfer Activities 83
Knowledge Products the Project Created 83
Knowledge Transfer Activities From this Project 83
CHAPTER 8: Conclusions and Recommendations 86
Standardization of Studies of Renewable Energy Impacts on Wildlife (Chapter 2) 86
Mitigation Practices at Renewable Energy Facilities (Chapter 3) 87
Development and Implementation of Tools to Identify Region of Origin of Wildlife Affected by Renewable Energy Facilities (Chapters 4 and 5) 87
Population Biology of Affected Species (Chapter 6) 88
Chapter 9: Benefits to Ratepayers 90

GLOSSARY AND LIST OF ACRONYMS 91

REFERENCES 93

APPENDIX A: Selection of Focal Species 1

Background 1

Decision-Making Framework 2

Decision-Making 3

Frameworks for Demographic Modeling 3

Reporting 5

Summary 6

Participants 7

APPENDIX B: Abstract from Published Paper "Effect of Heat and Singeing on Stable Hydrogen Isotope Ratios of Bird Feathers and Implications for Their Use in Determining Geographic Origin" 1

APPENDIX C: Details of Modeling Framework and Implementation 1

Modeling Framework 1

Model Implementation 2

LIST OF FIGURES

Page

Figure 1: Locations of Wind and Solar Energy Facilities Included in Wildlife Survey Assessments 13

Figure 2: Number of Reports from Renewable Energy Facilities 14

Figure 3: Number of Renewable Energy Facilities by Type 15

Figure 4: Number of Renewable Energy Facilities With Reports by Year 17

Figure 5: Number of Wildlife Use Survey Methods 19

Figure 6: Locations of Renewable Energy Facilities by Type Included in Mitigation Assessments 27

Figure 7: Number of Mitigation Reports from Renewable Energy Facilities 29

Figure 8: Mitigation Practices at Renewable Energy Facilities 30

Figure 9: Precipitation Isoscape 36

Figure 10: Flowchart of the Geographic Assignment Process 39

Figure 11: Sampling Locations, Precipitation Values, Accuracy, and Precision of Assignment for Golden Eagles 43

Figure 12: Relationship Between Accuracy and Precision 45
Figure 13: Distribution of Distances for Golden Eagles..46
Figure 14: Map of Sampling Sites 52
Figure 15: Priority Species from Which Feathers were Collected at Renewable Energy Facilities 59
Figure 16: Feather Hydrogen Isotope Values Collected From Priority Species 61
Figure 17: Biplot of δ^{13}C and δ^{15}N Values for Solar Fatalities 62
Figure 18: Percentages of Local vs. Nonlocal Geographic Origin 63
Figure 19: Fatalities by Month 64
Figure 20: Mean Population Growth Rate for 29 Species 75
Figure 21: Adult Survival, Productivity, and Population Growth Rate for 29 Species 76
Figure 22: Local and Nonlocal Individuals Killed at Renewable Energy Facilities 77
Figure 23: Mean Population Growth Rate for 12 Species Killed at Wind Facilities 78
Figure 24: Mean Population Growth Rate for 16 Species Killed at Solar Facilities 78
Figure 25: Adult Population Growth Rate, Survival, Productivity, and Percent of Local Individuals for 22 Species 79

LIST OF TABLES

Page

Table 1: Number of Reports from Renewable Energy Facilities...................................16
Table 2: Wind Energy Facilities Using the Same Survey Method for Pre- and Post-Construction Surveys...21
Table 3: Number of Individuals Sampled at Renewable Energy Facilities.....................49
Table 4: Priority Species for Study...50
Table 5: Summary of Wind Geographic Assignments for 12 Species 55
Table 6: Summary of Solar Geographic Assignments for 19 Species 56
Table 7: Prior Distributions for Survival and Fecundity Parameters for 34 Species 69
Table 8: Summary of Juvenile and Adult Survival Demographic Parameters for 34 Species...72
Table 9: Model Output for Demographic Parameters for 29 Species 74

EXECUTIVE SUMMARY

Background

Electricity generation has environmental impacts. This is the case even for renewable forms of energy like wind, solar, and geothermal. Many of these impacts affect wildlife, especially birds and bats. Moreover, these impacts are often compounded by threats from other human activities, such as land-use change, that reduce the quality of habitat. The combination of impacts can cause populations of species to decline, even to the point of near extinction and listing under the Endangered Species Act. Environmental costs associated with wildlife impacts increase the burden of permitting, developing, and operating a renewable energy facility. The costs associated with these increased challenges are then passed along to the ratepayers. Developing mechanisms to reduce the impacts of renewable energy generation on the species most significantly affected has economic, social, and environmental benefits.

Wind and solar energy facilities have collected extensive data on wildlife use and fatalities. To date, there has not been a comprehensive analysis to derive lessons about the general impacts on wildlife and the effectiveness of various mitigation strategies. These lessons could improve the operation and future development of renewable energy facilities with respect to reducing environmental impacts and associated stakeholder concerns.

Project Purpose

The overarching intent of this work was to gain a better understanding of the actual environmental impacts of renewable energy generation on sensitive species and habitats, using data from pre- and post-construction wildlife surveys conducted by wind and solar energy facilities. Three central challenges to addressing the impacts of renewable energy generation motivated this study:

1. Comparison of preconstruction predicted and postconstruction actual effects to sensitive species, as a foundation for improving predictive accuracy
2. Comparison of predicted and actual benefits of mitigation to sensitive species, as a foundation for improving predictive accuracy
3. Analysis of observed wildlife fatalities and habitat loss to determine whether the rate of fatalities would put populations of individual species at a high risk of decline.

This study addressed these central challenges with a high-tech, scientifically innovative approach that is being validated through peer-reviewed publications in scientific journals.

This work is important to help fill gaps in existing knowledge. First, past research suggested a weak relationship between predicted and actual effects of renewable energy generation; in other words, it predicted that counts of wildlife at a site before construction do not accurately predict the rate of fatalities. By implication, the same is true for predicting the effectiveness of mitigation for those effects. However, most of the work on this problem is from Europe and, as implementation of renewable energy and the ecosystems considered there are different, the nature of these relationships in California may also differ. Second, almost no knowledge exists on the population-level consequences of impacts to wildlife from renewable energy generation. This knowledge gap is in part because it has been difficult to understand the origin of wildlife killed at renewable energy facilities. For example, some waterbird species killed at solar energy plants in the Mojave Desert do not breed in California. Without knowing the origins of these populations and the number of birds in them, it is impossible to understand the effects of fatalities to those populations.

The information gathered and the tools and approach used in this study provide an implementation framework and technical standards that land and wildlife managers and permitting and regulatory agencies can use to assess progress towards reducing environmental impacts and lowering financial costs.

Project Approach

The study focused on flying species that are most affected by renewable energy facilities. To compare predicted assessments with actual observations of fatalities (Central Challenge 1) and of mitigation outcomes (Central Challenge 2), the project compiled databases of parameters obtained from pre- and postconstruction and pre- and postmitigation reports. These data were used to build simulation and statistical models to assess the modeled sensitivity or parameter importance of measured components (for example, acres conserved and number of fatalities) to identify key parameters whose quantification is associated with greater predictive accuracy. To understand how fatalities at renewable energy facilities affect the probability of persistence and demographic processes (that is, birth, death, and migration into and out of the area; Central Challenge 3), three steps were necessary:

1. Gather information on numbers of fatalities.
2. Identify the spatial extent of the population of interest (that is, estimate the size of the population affected by fatalities).
3. Build demographic models of those populations to assess their stability.

The authors developed a novel approach to identify the population of interest: a stable isotope analysis that reveals the origin of an individual based on geographic variation in hydrogen isotopes obtained from animal tissue. Subsequently, the authors used a conceptual framework designed by the U.S. Geological Survey to determine the most appropriate level of species-specific demographic modeling using the information available about each species. Limited data required simpler forms of the model; whereas, more complete data allowed development of more complex forms of the model.

Project Results

This project was successful in meeting project goals and objectives. The major findings of this work are as follows:

- Within California and in the United States in general, it is largely impossible to assess the utility of pre-construction surveys for wildlife to predict post-construction effects.
- There is limited standardization, repeatability, or useful experimental design in surveys conducted at renewable energy facilities within the state.
- Because only a subset of reports is available to researchers wishing to understand the effects of renewable energy facilities on wildlife, comparing predicted and expected effects either at a single renewable energy facility or across multiple facilities is nearly impossible.
- Mitigation at renewable energy facilities is either rarely conducted or rarely reported.
- Assessing broader population-level consequences of renewable energy facilities on wildlife requires understanding the origins of the wildlife affected by those facilities; the framework and tools in this report are one mechanism for understanding those origins.
- Between 24 and 100 percent of individuals of the study species killed at renewable energy facilities were nonlocal in origin (they grew their feathers far from the site where they died).
- The nonlocal wildlife killed at renewable energy facilities in the state were predominantly from outside California.
- A lack of basic biological and natural history information about these species in California and neighboring states creates a challenge for understanding the demographic impacts of those fatalities.
- Integrating Bayesian population modeling (a mathematical procedure that applies probabilities to statistical problems) with stable isotope data provides one useful mechanism to extract information from these limited data.
- Of the species killed, those of predominantly local origin were especially likely to have lower population growth rates (that is, they were declining) and greater adult survival (that is, they were long-lived species).

Improvements to survey design, report availability, analytical methods, and information gathering would allow more accurate scientific assessment of the effects to wildlife of renewable energy generation and improve the ability of managers to address those effects. These include:

- Implementation and standardization of pre- and postconstruction surveys and mitigation programs at renewable energy facilities and the incorporation of experimental design principles into those surveys and programs.

- A central repository for reporting results of pre- and postconstruction surveys and programs.
- Assessment of effects to wildlife populations from renewable energy not just within California but also well beyond the state borders.
- Collection of more baseline biological and natural history information for many species affected by fatalities at renewable energy facilities.

Knowledge Transfer

This project created a series of specific knowledge products and transfer activities targeted at wildlife and land managers and state and federal permitting, research, and regulatory agencies (California Department of Fish and Wildlife, US Fish and Wildlife Service, US Bureau of Land Management, US Geological Survey), as well as their partners in the renewable energy industry, the non-profit arena (California Audubon), and academia (Oklahoma University). The framework for reporting these products includes this report, several public and private presentations to the target audience, such as at conferences organized by the American Wind Wildlife Institute and its partners, and scientific manuscripts to *Biological Conservation* and other journals that provide peer-reviewed validation for the approach and findings.

Benefits to California

This project produced several benefits to ratepayers. It provides concepts to reduce the costs of environmental management, which can influence the reliability of energy delivery. The project also provides a framework and specific tools for understanding environmental impacts of renewable energy generation. The approach taken here is a framework that others can use to achieve similar goals. Finally, this project offers numerous qualitative benefits to California investor-owned utility ratepayers, through improved predictions of the environmental effects of renewable energy generation, reduction of the environmental impacts of those effects, and increased certainty in the regulatory environment.

CHAPTER 1: Introduction

Electricity generation has environmental impacts. This is the case even for renewable forms of energy—wind, solar, and geothermal (Katzner et al. 2013). Many of these impacts affect wildlife, especially birds and bats. Wind and solar energy generation can injure or kill large numbers of volant wildlife (direct effects) and can also reduce habitat quantity and quality for these same species (indirect effects).

Although it is well established that environmental permitting and compliance add both costs and benefits to industry (Economist 2014), the environmental costs associated with wildlife impacts increase the cost of electricity for ratepayers because they increase the challenges to permitting, developing, and operating a renewable energy facility. Beyond the financial costs, in the face of the modern biodiversity crisis (Yin, He, and Xie 2011), there is public pressure to reduce excessive impacts to wildlife. Therefore, there are economic, social, and environmental benefits to developing mechanisms to reduce the environmental impacts of renewable energy generation. Reducing such impacts is especially important to California, which aims to supply 100 percent of electricity from eligible renewable energy resources and zero-carbon resources by 2045 (Senate Bill 100, De León, Chapter 312, Statutes of 2018).

The number of renewable energy facilities within California has increased rapidly in the past decade. Most of these facilities have conducted pre- and post-construction surveys to assess potential and actual impacts to wildlife. However, these data have not been synthesized to develop lessons for future operation and to develop protocols for minimizing impact to wildlife. This project responds to three central challenges to mitigating the impacts of renewable energy generation:

1) Comparison of pre-construction predicted and post-construction actual effects to sensitive species, as a foundation for improving predictive accuracy
2) Comparison of predicted and actual benefits of mitigation to sensitive species, as a foundation for improving predictive accuracy
3) Analysis of observed wildlife fatalities and habitat loss to determine the significance of fatalities to population persistence

These central challenges to mitigating impacts of renewable energy generation focus on assessment of the demographic mechanisms and geographic scopes of effects on wildlife (and by inference, assessment of population persistence, locally and nationally). For example, golden eagles (*Aquila chrysaetos*) are among the most high-profile and well-studied species affected by wind energy development in California. At the Altamont Pass Wind Resource Area (APWRA) in the Diablo Range (managed in part by NextEra Resources, which has a power purchase agreement with Pacific Gas and Electric), large numbers of golden eagles are struck and killed by turbine blades. The problem of golden eagle mortality at the APWRA has been recognized and studied since shortly after the facility was originally constructed less than 30 years ago (Hunt 2002; Smallwood and Thelander 2008) so the approximate number of eagle fatalities at APWRA per year is known. However, a central question – whether these fatalities are sustainable for golden eagle populations at local, regional, and continental scales has only recently been answered by this report's team (Katzner et al. 2017). The question remained unanswered for more than two decades because the spatial and, thus, demographic scope of these fatalities was unclear; the same is true for every other volant species affected by energy development.

The vast majority of population models are limited to populations with a known geographic scope (Katzner, Bragin, and Milner-Gulland 2006; Coulson et al. 2011) or focus on range-restricted species (Schumaker et al. 2014). These models do not have to characterize the spatial extent of the population they are modeling because it is defined by the biology of the organism in question. However, understanding the demographic impact of fatalities at renewable energy facilities in California or elsewhere requires careful identification of the population of interest: that population from which fatalities are drawn. Without such knowledge, demographic models are likely to be highly misleading (for instance, demographic models developed for state boundaries would be biologically arbitrary and, thus, not an appropriate mechanism to use to answer the questions in this study).

The problem of the scale of impact is well demonstrated by APWRA eagles. The number of golden eagle territories in and around the APWRA appears stable (Hunt 2002); however, demographic data and models suggest that the rates of fatalities caused by wind turbines should cause the local population to decline (that is, the finite growth rate, $\lambda \leq 1.0$). Thus, the local population must be augmented either by atypically high reproduction, by high pre-adult survivorship, or by high immigration from other populations.

Effective management for golden eagles, therefore, depends on identifying the origins of these extra APWRA eagles, or, in demographic terms, on identifying the geographic extent of this population. For example, if the population of golden eagles at APWRA is sustained by high reproduction and survivorship, then golden eagle fatalities at APWRA are an issue of local concern. Alternatively, if the population of golden eagles at APWRA is sustained by immigration of individuals from elsewhere in North America, then golden eagle fatalities at APWRA are an issue of regional and perhaps continental concern as well.

Uncertainty about the demographic scope of the population from which fatalities are drawn applies to every species killed at turbines in the APWRA and all other California wind and solar facilities, regardless of whether red-tailed hawks (*Buteo jamaicensis*), American kestrels (*Falco sparverius*), burrowing owls (*Athene cunicularia*), or any other species of bird or bat known to experience mortality at renewable energy facilities in California is considered.

Two other challenges associated with renewable energy development lie in accurate prediction of (1) impacts (fatalities) of the energy production process; and (2) benefits of mitigation actions. These challenges are important because few examples exist of effective Before-After-Control-Impact (BACI) studies at renewable energy facilities. The state-of-the-art to evaluate accuracy of predicted impacts (pre-construction monitoring) or mitigation outcomes is at least as poorly developed as is that for identifying the population of interest. There are few peer-reviewed journal articles on this topic; two exceptions are a study in central British Columbia showing changes in flight behavior of eagles in response to the presence of turbines (Johnston, Bradley, and Otter 2014) and a study in Spain showing a weak relationship between pre-construction assessment and actual fatality rates (Ferrer et al. 2012). There are a number of well-established agency protocols for pre-construction assessment (U.S. Fish and Wildlife Service 2012, 2013; Pennsylvania Game Commission 2013) and at least one agency study of pre- and post-construction survey relationships for bats (Hein, Gruver, and Arnett 2013). In general, these call for pre-construction surveys and, in a few cases, post-construction surveys (Pennsylvania stands out in this regard). Mitigation is rarely mentioned, except as it pertains to sustainable take of eagles (U.S. Fish and Wildlife Service 2013) and curtailment for bats (Arnett et al. 2011).

The Approach

This study addressed these central challenges with a high-tech, scientifically innovative approach that was peer-reviewed via publication in scientific journals. To compare predicted assessments against actual observations of fatalities (central challenge #1) and of mitigation outcomes (central challenge #2), the project had to compile databases of parameters obtained from pre- and post-construction and pre- and post-mitigation predictive reports. These data could then be used to build simulation and information-theoretic statistical models to assess the modeled sensitivity or parameter importance of measured components (for example, fatalities, acres conserved), in these reports to identify key parameters whose quantification is associated with greater predictive accuracy. To understand how fatalities at renewable energy facilities affect the probability of persistence and demographic processes (central challenge #3), three steps were necessary:

1) Gather information on numbers of fatalities
2) Identify the spatial extent of the population of interest (that is, estimate the size of the population affected by fatalities)
3) Build well-parameterized demographic models of those populations to assess their stability.

Identification of the population of interest relied on a novel approach to stable isotope analysis developed by the authors. Subsequently, the authors used a conceptual framework designed by the U.S. Geological Survey (USGS) to characterize the appropriate level of species-specific demographic modeling using the information available about each species.

With this information in hand, it was possible to model the demography of these populations. The approach used here – stable isotopes to identify the population of interest and subsequent demographic modeling for that population – is novel and has, to the authors' knowledge, only been used once to understand fatalities at renewable energy facilities. That one scenario was this team's work with golden eagles killed at the APWRA (Katzner et al. 2017). This challenge, of identifying the *catchment area* of a mortality source, has been conceptually recognized as a major issue for understanding population-level impacts of anthropogenic mortality (Loss, Will, and Marra 2012), but to the authors' knowledge, there were no peer-reviewed studies on this problem.

In spite of the paucity of carefully designed BACI studies, the authors expected to be able to broadly compare pre-construction risk-assessment studies and their post-construction outcomes to generate quantitative assessments of prediction accuracy and mitigation outcomes. This unfortunately was not possible, although this work provided important insight into ways that pre- and post-construction and pre- and post-mitigation surveys can be conducted to improve their comparability (see chapters 2 and 3). The stable isotope approach was effective at inferring the population of origin of wildlife killed at renewable energy facilities (chapters 4 and 5). Finally, these data were integrated into demographic models that provided insight into the population-level effects of renewable energy on these species of wildlife (Chapter 6).

CHAPTER 2: Assessing Standardization in Californian Studies of Renewable Energy Impacts on Wildlife

Introduction

Informed siting of energy facilities is one of the most common strategies to avoid and minimize risk to wildlife populations. Conducting appropriate pre-construction risk assessments and collecting appropriate post-construction fatality data are important steps to effectively estimate effects from construction and operation and, therefore, to improve siting decisions. State and federal agencies with responsibility for managing wildlife resources often recommend or, in some cases, require that information thought to be relevant to predicting impacts to wildlife be collected in pre-construction surveys (Strickland et al. 2011; Huso et al. 2016; Huso, Dietsch, and Nicolai 2016; Katzner et al. 2016). That information is intended to help answer questions such as how to avoid negative impacts to wildlife species of concern, what has been learned from past experience to better site renewable energy facilities, and whether the right information is being collected to improve siting efforts. In turn, actual impacts are estimated from surveys during post-construction operation.

In pre-construction surveys, state and federal siting guidelines recommend point counts, nest searches, and/or other approaches intended to predict possible adverse effects by quantifying presence and activity of species of concern potentially exposed to the proposed energy facility (Martin and Geupel 1993; Ralph, Sauer, and Droege 1995; Katzner et al. 2016). Siting guidelines also recommend specific protocols for estimating impacts during construction and operation of an energy facility. Typically, carcass searches are conducted to estimate the number of individual birds or bats killed during the period of facility operation (U.S. Fish and Wildlife Service 2012; Huso et al. 2016).

Despite frequent calls for an increase in data rigor and study design, especially for post-construction fatality surveys (U.S. Fish and Wildlife Service 2012), the degree to which the previously described benefits can be realized is unclear; the extent to which survey methods are systematically conducted has never been explicitly quantified. For example, pre- and post-construction surveys often use differing survey types between construction periods (for example, wildlife activity or habitat use surveys and carcass counts, respectively), which may hamper empirical assessment of cumulative impacts and the total number of animals killed (Loss, Will, and Marra 2013) and the ecological or population-level significance of those fatalities. Further limiting comparisons between datasets, wildlife use surveys may be taxa–(for example, nocturnal acoustic surveys for bats) or species–(golden eagle nest surveys) specific and each survey type monitors different variables, such as abundance (for example, point counts, migration surveys), habitat use (for example, behavioral observations), or reproductive behavior or success (for example, nest searches). If pre- and post-construction survey methodologies are not consistent across facilities or through time, it may be necessary to exclude data collected with inconsistent protocols or to evaluate more rigorously what methodologies must be consistently applied to allow for valid predictions of fatality rates at a project or comparison of fatality rates across projects (U.S. Fish and Wildlife Service 2012; Argonne National Laboratory and National Renewable Energy Laboratory 2015a; Huso et al. 2016; Huso, Dietsch, and Nicolai 2016).

This study reviews the extent to which data collection and analysis approaches for fatality and wildlife use are standardized across pre- and post-construction surveys and among different energy facilities. Specifically, it focuses on three key questions:

1) How frequently are both pre- and post-construction surveys implemented and how have survey methodologies for both pre- and post-construction surveys evolved over time?
2) How frequently are studies explicitly designed to allow before-after or impact-control analyses?
3) Independent of the degree of standardization of data types between pre- and post-construction surveys and among energy facilities, what types of existing information from pre- and post-construction surveys can be used to assess effects of renewable energy facilities on wildlife populations?

Finally, it proposes a series of best practices for pre- and post-construction surveys to improve the utility of future datasets. The goal of this study is to increase the ability of these surveys to accomplish their specific objectives – risk and impact assessment at individual projects – and facilitate the ability of analyses from these cumulatively large datasets to minimize the impacts of future projects, thus contributing to wildlife conservation while achieving clean energy goals.

Methods

Literature Search

The authors conducted a literature search using online search engines and publicly available document collections to locate peer-reviewed literature and unpublished reports (hereafter "reports") containing pre- or post-construction wildlife survey data from proposed and operating wind and solar facilities in California. They restricted their scope to surveys on birds and bats. In Google Scholar and Web of Science, they used the keywords "wind turbine," "wind," "solar," "mortality," "wildlife use," and "carcass search" along with the names of individual renewable energy facilities. The authors also compiled reports available from public databases with information on California facilities (American Wind Wildlife Institute 2017; California Energy Commission 2017; National Renewable Energy Laboratory 2017; Pacific Northwest National Laboratory 2017). They also solicited reports from federal, state, and county agencies and accessed data summarized in previous reviews of renewable energy impacts on birds (Loss, Will, and Marra 2013) and bats (Thompson et al. 2017). Additionally, they obtained previously compiled publicly available reports for facilities in California from the U.S. Fish and Wildlife Service (USFWS; Heather Beeler, pers. comm.). They also used Google to search and locate additional reports not in other document collections or indexed in scientific literature databases and checked published bibliographies (Biosystems Analysis and IBIS Environmental Services 1996; Western EcoSystems Technology and Bat Conservation International 2014; Argonne National Laboratory and National Renewable Energy Laboratory 2015b) and reference lists from compiled reports.

Data Organization

The authors extracted from each document information about the renewable energy technology used at each facility (for example, wind, photovoltaic solar, solar trough, power tower), dates wildlife surveys were conducted, the facility construction phase studied (pre- and/or post-construction), and whether the study used either an experimental study design with both reference and control sites or before and after construction analyses. They also recorded the specific type of survey data collected (for example, fatality [carcass] or wildlife use surveys) and information about the survey techniques used (for example, search frequency, survey area), including whether studies included trials to estimate and correct for biases associated with raw carcass counts (for example, searcher detection efficiency and carcass removal, proportion of area searched) or for detection probability of live animals in wildlife use surveys. The authors restricted their analyses to birds and bats because these have been the primary taxa monitored at renewable energy facilities.

For some facilities, multiple reports provided information on overlapping time periods. For example, some facilities had monthly reports as well as annual reports that summarized all monthly reports. To avoid double-sampling in these cases, the authors excluded the reports covering the shorter time period. They also excluded pre-construction reports for proposed facilities that were never completed, for those facilities currently under construction or that were recently completed but for which post-construction data were not yet available, and if they were unable to determine which wind facilities were studied. Finally, they recorded citation data for reports listed in bibliographies and reference lists that could not be located during literature searches or obtained from study authors or the agency or company requesting the report. For these reports, the authors extracted and incorporated information about the construction phase, facility name, and survey dates when this information was available in the title and incorporated these data into analyses as appropriate. For example, the authors included citation-only records when summarizing the number of studies from each facility type and for which wildlife monitoring occurred, but not for analyses that required actual monitoring results unless other reports specifically described the survey types used in these missing documents.

Naming Conventions

The authors assigned locations for each report using the overall facility name (hereafter *facilities*) and used facility as the unit of replication. While some facilities further defined *subunits* based on construction phases or multiple owners, sublocations within the same facility are usually monitored by the same entities with the same methodologies and, as such, the authors could not always determine if sublocations were independent sampling units. Thus, the results provide a conservative interpretation of the minimum expected differences across facilities; these differences may be larger if subunits were sampled independently.

Data Analysis

The authors summarized report data by facility and construction phase and identified if there was variation in survey methods across facilities and years. Additionally, analyzing data for wind and solar energy separately, they created contingency tables and calculated Fisher's exact test values with package vcd (Meyer, Zeileis, and Hornik 2016) in R 3.4.0 (R Core Team 2017) to assess whether the frequency with which different construction phases monitored (pre-, post-, or both) changed depending on the year of initial operation of each facility.

The authors identified facilities that had pre- and post-construction monitoring data and that incorporated undeveloped reference sites as controls. They used the same analyses as above to determine if the incorporation of experimental design at facilities changed with the initial operation year of the facility (response variable). Finally, the authors calculated summary statistics to quantify differences in survey methods between pre- and post- construction phases and among different energy facilities. They used Fisher's exact tests to examine potential differences in the type of survey data collected between energy types and construction phases. They defined survey methods as *breeding site surveys* (for example, nest searching), *taxon or status-specific surveys* (for example, surveys for a single species), and *population size estimation* (for example, point counts for birds).

Results

Frequency of Pre- and Post-Construction Surveys and How Survey Methodologies Have Evolved Over Time

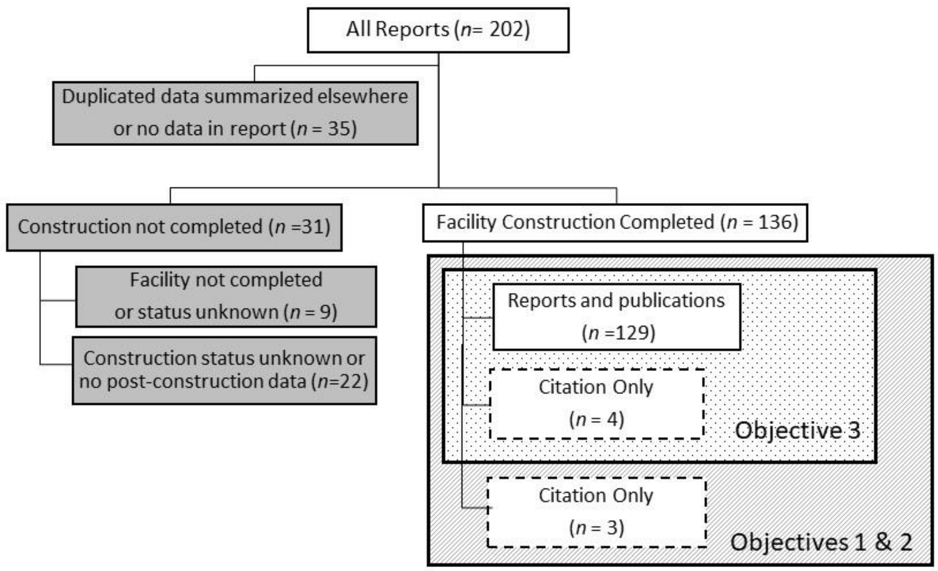
The authors compiled information in 202 reports from 46 facilities in California (Figure 1). Thirty-five reports contained data summarized elsewhere and were removed from subsequent analysis. The authors excluded 9 additional reports from 5 facilities that were never constructed and 22 reports from 10 facilities where construction was not yet completed or the facility did not yet have post-construction data available. Thus, the analyses focused on 136 reports from 30 facilities (Figure 2). For seven of these reports from five facilities, the authors found citations, but not the original reports and thus were able to compile data based on those citations.

Figure 1: Locations of Wind and Solar Energy Facilities Included in Wildlife Survey Assessments

Locations of wind and solar energy facilities used to assess wildlife surveys at renewable energy facilities.

Source: U.S. Geological Survey

Figure 2: Number of Reports from Renewable Energy Facilities

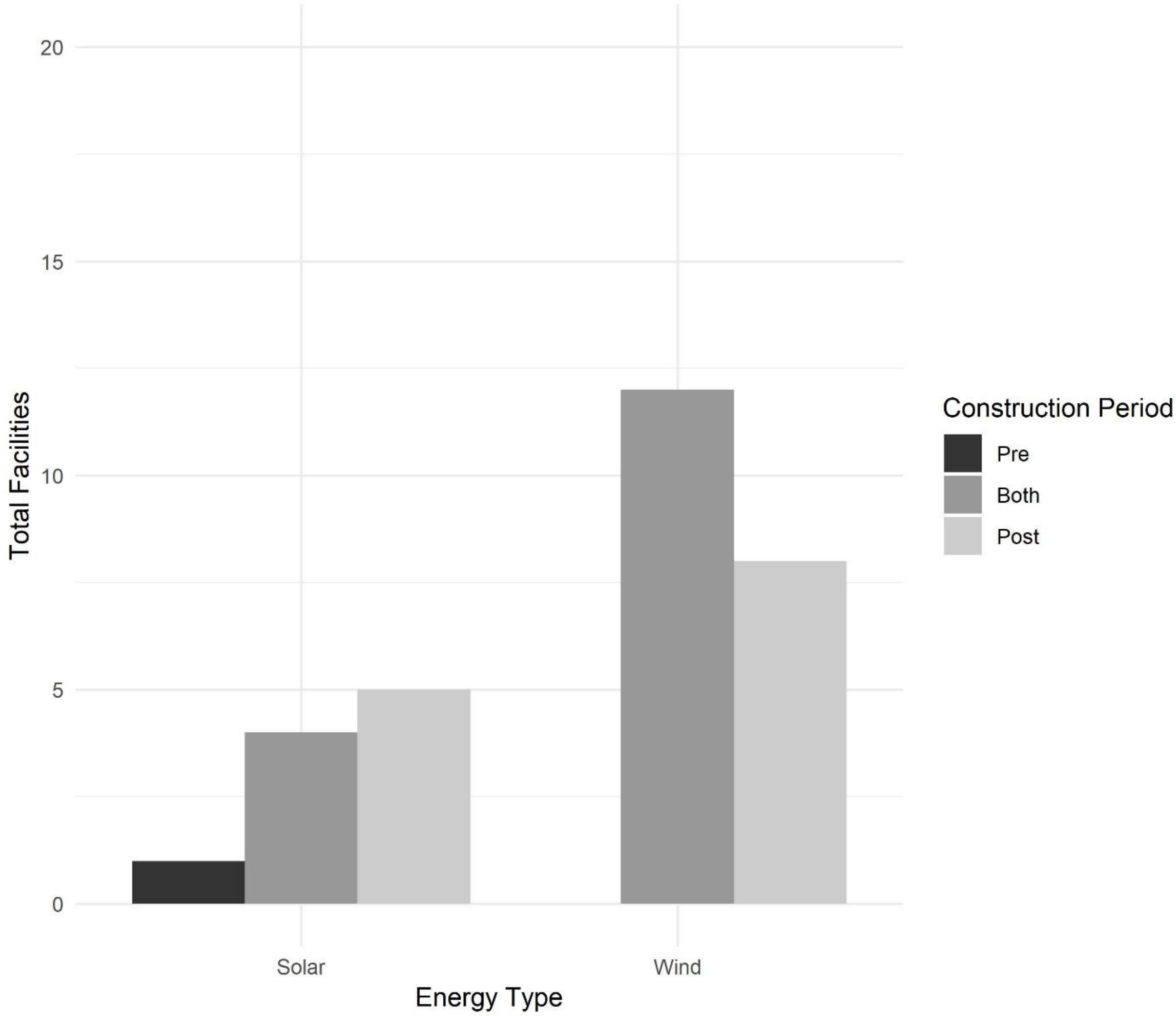


Number of reports on pre- and post-construction monitoring at renewable energy facilities. Categories of reports in dark gray boxes (left) were not included in analyses to assess wildlife surveys at renewable energy facilities reported in this study. Categories of reports in white boxes were included in this study. Figure also shows which reports were used to answer each research objective outlined in the introduction to this chapter.

Source: U.S. Geological Survey

The majority (*n* = 81; 59.6 percent) of reports in the dataset were for wind facilities. When considering both renewable energy types, most surveys (*n* = 104; 76.5 percent) were for the post-construction period (Figure 3). Most (*n* = 87, 64.0 percent) reports collected data on both birds and bats, although 46 reports (46.9 percent of wind reports [*n* = 38] and 14.5 percent of solar reports [*n* = 8]) focused exclusively on avian species. Only 15 facilities (50.0 percent; 4 solar facilities and 11 wind facilities) had data on fatalities or wildlife habitat use for multiple construction phases (Table 1). Whether data existed for pre-construction, post-construction, or both phases (Figure 4) was not influenced by initial year of facility operation for either wind (*P* = 0.18) or solar energy (*P* = 0.86). The latter result may have been influenced by the small number of operational solar facilities in the data set (*n* = 10) and the short time period during which solar energy development has existed (since 2013). There was also no effect of initial operation year when the response variable was restricted to only two categories (that is, data existed for one phase [either pre- or post-construction] or both phases; wind: *P* = 0.13; solar: *P* = 0.46).

Figure 3: Number of Renewable Energy Facilities by Type



Number of renewable energy facilities in California (1981–2016) from which the authors were able to gather monitoring reports on surveys conducted pre-construction, post-construction, or during both construction phases. Data are sorted by renewable energy type.

Source: U.S. Geological Survey

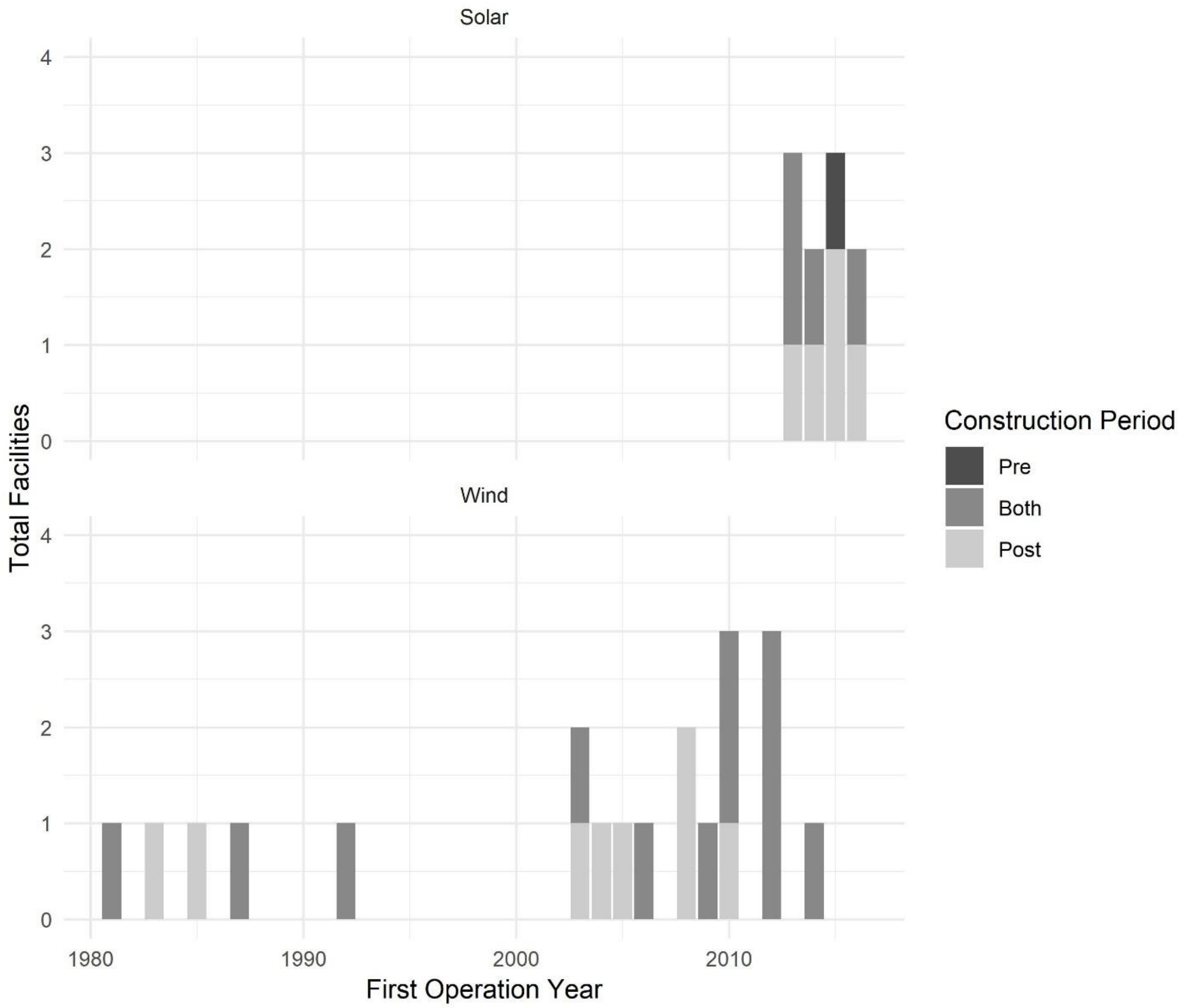
Table 1: Number of Reports from Renewable Energy Facilities

Type	Facility Name	Construction Period			Same Survey Method
		Pre	Both	Post	
Solar	Blythe Solar Energy Center	6	0	1	No
	California Valley Solar Ranch	1	0	3	No
	Campo Verde Solar Facility	1	0	2	No
	Genesis Solar Energy Center	3	0	3	No
Wind	Alta	3	0	13	Yes
	Hatchet Ridge	1	0	2	No
	High Winds	0	1	1	Yes
	Manzana Wind	2	0	8	Yes
	Montezuma Hills	4	1	1	Yes
	North Sky River	1	0	5	No
	Ocotillo	3	0	1	Yes
	Pine Tree	1	0	2	No
	Rising	1	0	1	Yes
	Shiloh	2	0	9	Yes
	Tehachapi	1	0	3	No

Total number of reports used for analyses for renewable energy facilities in California (1981–2016) that included monitoring during multiple construction periods (that is, pre-construction, post-construction, or both periods).
Also shown is whether or not that facility used the same survey method during both monitoring periods.

Source: U.S. Geological Survey

Figure 4: Number of Renewable Energy Facilities With Reports by Year



Type of monitoring conducted at renewable energy facilities in California for which reports were collected. Data are sorted by year during the period 1981–2016; solar and wind are shown separately.

Source: U.S. Geological Survey

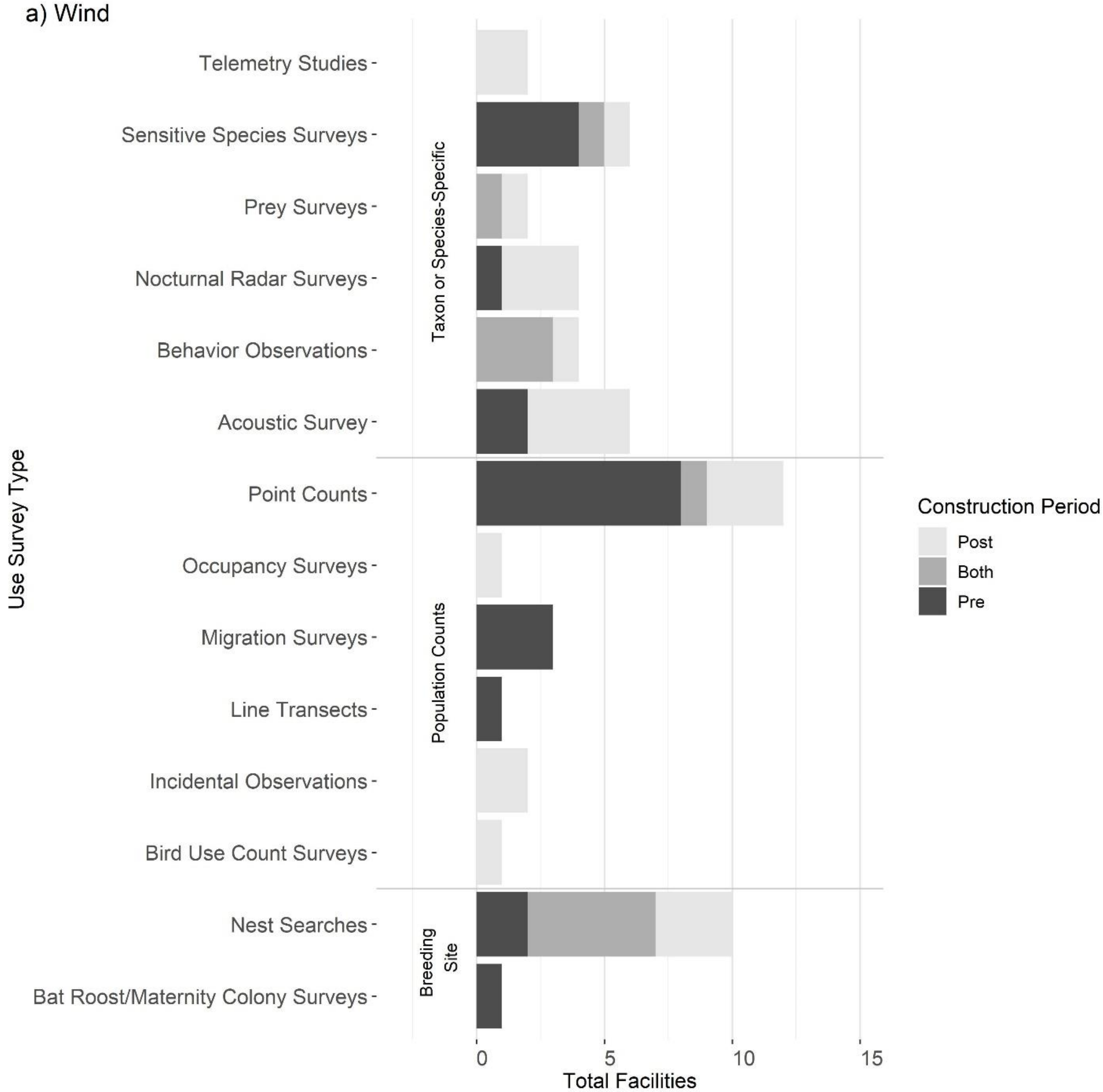
Frequency of Experimental Design Elements in Surveys

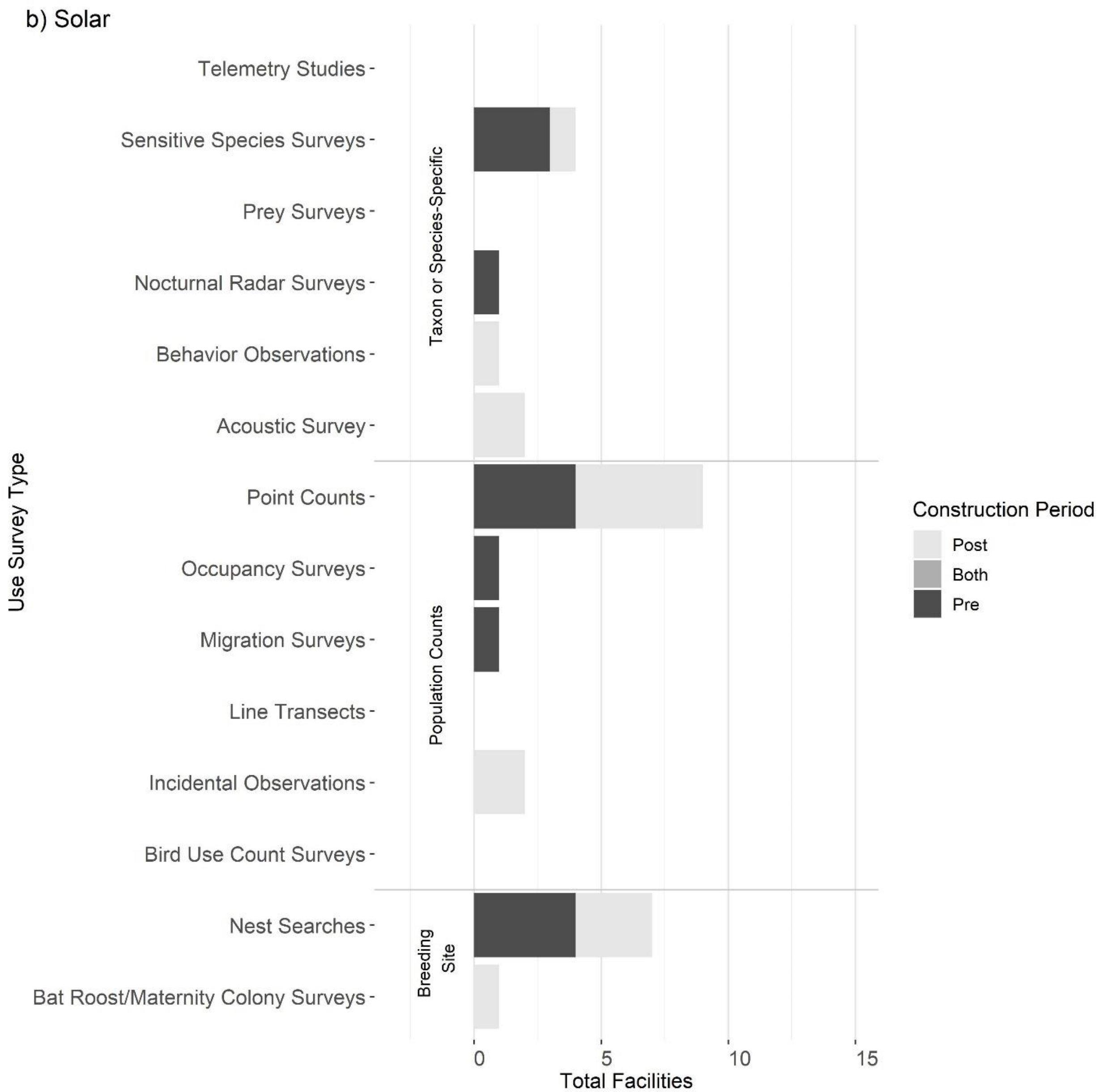
Reports from nine facilities (30.0 percent) incorporated some element of experimental survey design to compare effects between pre- and post-construction phases or to compare facility impacts with nearby control sites. However, the frequency of experimental design elements did not vary with initial facility operation year for wind (P = 0.99) or solar (P = 0.75).

Degree of Data Standardization Across Pre- and Post-Construction Surveys and Among Facilities

To characterize the types of survey data collected and the standardization of survey data types collected during pre- and post-construction phases and among facilities, the authors used a reduced data set of 133 reports (30 facilities) that excluded three citation-only records with no information about survey methods (Figure 2). However, they were able to include four citation-only records because other reports explicitly described the survey types used in these missing reports. In addition to fatality surveys, 14 other survey types were used to quantify habitat use at facilities (Figure 5). Fatality surveys (n = 87 reports) were conducted almost exclusively (98.8 percent) during post-construction periods. Conversely, other use survey techniques were more prevalent during both pre- and post-construction phases, regardless of facility. These included point counts (n = 58 total reports; 65.5 percent during post-construction), behavioral observations (n = 12 total; 83.3 percent during post-construction), nest searches (n = 40 total; 67.5 percent during post-construction), and acoustic surveys (n = 11 total; 72.7 percent during post-construction).

Figure 5: Number of Wildlife Use Survey Methods





Types and numbers of wildlife use survey methodologies applied at renewable energy facilities in California during the period 1981–2016. Data are broken out by the phase when each facility used that survey method (pre-construction, post-construction, or both); a) wind and b) solar energy generation are shown separately.

Source: U.S. Geological Survey

Only 7 of 30 (23.3 percent) facilities (all of them wind facilities) used the same habitat use survey approaches during pre-and post-construction phases (Table 2, Figure 5). Three of these seven facilities (42.9 percent) were those identified as incorporating elements of experimental study design. The type of habitat use survey implemented (Figure 5) was not related to the facility's initial operation year for either wind (breeding site: $P = 0.80$; population counts: $P = 0.78$; taxon or species-specific: $P = 0.58$) or solar (breeding site: $P = 1.00$; population counts: $P = 1.00$; taxon or species-specific: $P = 1.00$).

Table 2: Wind Energy Facilities Using the Same Survey Method for Pre- and Post-Construction Surveys

Location	Area Search	Acoustic Survey (Bats)	Behavior Observations	Migration Surveys	Mist Net	Nest Searches	Nocturnal Radar Surveys	Point Counts	Prey Surveys	Sensitive Species Surveys	Waterfowl Surveys	Experimental Study Design
Alta						X						No
High Winds						X		X	X			Yes
Manzana Wind			X									Yes
Montezuma Hills			X			X						No
Ocotillo Wind										X		No
Rising Tree Wind						X						No
Shiloh			X			X						Yes

Wind energy facilities with documented pre- and post- construction surveys using the same survey method during both monitoring periods (Objective 3). Also noted is whether that facility incorporated experimental study designs during facility surveys (Objective 2).

Source: U.S. Geological Survey

All 30 facilities had information about survey methods, and most of these (76.7 percent) incorporated searcher efficiency and carcass persistence trials or data when conducting fatality surveys to account for detection probabilities of carcasses that were present but not seen by observers. In contrast, only 6.7 percent ($n = 2$) of facilities monitoring avian habitat use with other survey methods (for live animals) incorporated sampling approaches (for example, mark-recapture, distance sampling) to quantify detection.

Discussion

With the increased development of renewable energy facilities, surveying and monitoring wildlife populations to assess potential risk and realized impacts of renewable energy technologies is an important aspect of effective conservation management and regulatory compliance. However, differences in the metrics collected, a lack of pre- versus post-construction data relative to a primary focus on post-construction data collection, and limited availability and accessibility of those data for public use limits the effectiveness of current monitoring practices in addressing the broader questions about the impacts of renewable energy development.

Surveys at renewable facilities are primarily motivated by local and federal siting guidelines (for example, U.S. Fish and Wildlife Service 2012). Additional scientific rigor at relevant spatio-temporal scales, with appropriate estimation of detection probabilities, will enhance the ability of pre- and post-construction surveys to fulfill the goal of predicting the effects of future energy facilities on wildlife or about the effectiveness of particular impacts mitigation practices (Ferrer et al. 2012; Huso et al. 2016). Additionally, systemization of survey monitoring, analytical approaches, and the questions addressed across facilities can allow for regional-, national-, and continental-scale analyses of the effects of renewable energy on wildlife populations.

Frequency of Pre- and Post-Construction Surveys

Post-construction monitoring for wildlife fatalities at renewable energy facilities was a common component of reports in the dataset. However, only 50 percent (n = 15) of the facilities collected data of any type during both the pre- and the post-construction phases. While there have been a large number of newly operational facilities with available reports in recent years (Figure 4), the authors did not observe an increased emphasis on pre-construction surveys at those facilities. Because inferences are limited to the reports available through the literature search strategy, the totals represent the best possible estimates given the lack of availability of reports and data.

Post-construction fatality surveys can indicate the number of individual birds or bats killed during the period of facility operation (Huso 2011). However, without the context provided by pre-construction or reference-site surveys, these totals may not characterize the biological significance of fatalities for local or regional populations.

Frequency of Experimental Design Elements in Surveys

Of the 15 facilities where data were collected during both pre- and post-construction phases, 60 percent incorporated some element of experimental survey design to identify renewable energy effects. Implementation of BACI studies or other rigorous experimental designs may not always be possible due to logistical and financial constraints that limit data collection across multiple seasons or at control sites. Finally, the majority of studies were likely designed with the intention of meeting requirements or guidelines of federal or state environmental impact statements or reports. Such guidelines often mandate surveys that are not designed to address specific research questions or to experimentally assess impacts on wildlife.

Degree of Data Standardization Across Pre- and Post-Construction Surveys and Among Facilities

Only seven facilities in the dataset (23 percent of 30 facilities with information about survey methods and 47 percent of 15 facilities with both pre- and post- data) collected the same biological data pre- and post- construction (Table 2). Not coincidentally, 43 percent of these seven facilities were those identified as incorporating elements of experimental study design.

Protocols developed by Huso et al. (2016), Huso, Dietsch, and Nicolai (2016), and the National Wind Coordinating Collaborative (Strickland et al. 2011) provide guidance toward standardized data collection and analyses during fatality surveys. However, there is limited information regarding standardized procedures for pre-construction population surveys (Katzner et al. 2016). Such guidance is necessary to best inform study designs for pre-construction surveys aimed at appraising the potential impact to wildlife populations of proposed renewable energy facilities.

A limitation of potentially greater concern is that wildlife use surveys evaluated by the authors rarely less than 7 percent of the time) included methods to estimate detection probabilities of live animals. Because detection rates are never 100 percent, it is essential to correct count data for detection probability to account for animals that were present but undetected. In recent years, distance sampling (Buckland et al. 2001; White 2005; Western EcoSystems Technology 2009; Sollmann et al. 2016), N-mixture models (Royle 2004; Kéry, Royle, and Schmid 2005; Royle and Dorazio 2008; Sillett et al. 2012), and an array of other analytical approaches allow relatively straightforward estimation of, and adjustment for, detection probabilities for estimates of wildlife abundance.

Because detection probabilities are not estimated during abundance sampling, and because of the substantial variation in both pre- and post-construction survey approaches among studies, it is difficult to compare wildlife abundance data across facilities. That said, minimal changes to existing sampling designs would be required to generate data that allows estimation of detection probability.

Limitations and Recommendations for Increased Data Availability

A number of caveats must be considered when interpreting these results. In particular, in spite of the relatively large sample size (30 facilities; Figure 1), the authors did not acquire reports for every facility with active renewable energy facilities. There are a number of reasons that not every report was available, including regulatory and privacy concerns as well as time lags on releasing reports from recently constructed facilities.

A mechanism to address this data availability issue may be through voluntary submission of monitoring records to a central repository. Although voluntarily submitted data may not be completely representative of the overall population, a publicly available repository for data collected at renewable energy facilities would have tremendous benefit. The American Wind Wildlife Institute (AWWI) has taken steps in this regard by compiling a public document library including peer-reviewed literature and nonpublished reports from multiple wind energy facilities in North America (AWWI 2017).

Improving Monitoring at Renewable Energy Facilities

This study identifies several key areas where improvements to the science supporting monitoring at renewable energy facilities and to data accessibility would be mutually beneficial to both renewable energy producers and wildlife conservation efforts. In particular, the authors emphasize the following best management practices:

- Design: when appropriate, experimental study design that has pre- and post-construction monitoring, a control site, or a BACI design
- Implementation: field protocols that incorporate the same type of monitoring across experimental units and that include detection rates for both fatalities and for wildlife habitat use
- Dissemination: reporting protocols that allow corporations to protect aspects of data they view as confidential while allowing use of wildlife data to be analyzed by others in comparative studies

The dataset illustrates the challenges associated with aggregating existing wildlife surveys at renewable energy facilities, and it also shows that effective monitoring has been conducted at some facilities and, therefore, should be possible at a large proportion of energy facilities in the future. The authors take this as evidence that the path toward improved understanding and mitigation of renewable energy's impacts on wildlife may not present insurmountable obstacles. Continued advances in sampling methodologies will further allow wildlife managers and industry to more accurately, and cost-effectively, anticipate and estimate numbers of fatalities associated with operation of renewable energy facilities. Improvements in these areas are also the foundation for identification of the effects of these fatalities on local and regional wildlife populations and, thus, for effective conservation management of wildlife in response to continued renewable energy development. They would also facilitate comparisons of the relative losses caused by renewable energy development with those from climate change if the renewable energy development did not occur.

CHAPTER 3: Mitigation Practices at Renewable Energy Facilities in California and North America

Introduction

There is increased interest by energy industry, policy makers, and conservation professionals to offset take of wildlife populations through mitigation practices at energy facilities. These practices frequently are designed either to directly modify habitat or animal behaviors to minimize fatalities—for example, removal of turbines or guywires to reduce collision risk, visual deterrents to alter flight patterns (May et al. 2015; Arnett and May 2016) or to provide alternative habitat to offset areas adversely impacted by the facility (McKenney and Kiesecker 2010). However, within the renewable energy industry, mitigation is often broadly categorized to include practices to identify affected populations (for example, wildlife use surveys, nest monitoring) or to reduce and minimize facility effects. These practices include designs to limit habitat modification during construction and facility operations, reductions of disturbances to existing wildlife populations, and minimizing wildlife fatalities through macro- and micro-siting decisions based on existing wildlife populations. Mitigation practices can also include modifications to existing or future facility infrastructure including perimeter fences, evaporation ponds, and solar units to reduce collisions, drowning, or singeing incidents involving wildlife.

Understanding use and reporting of mitigation practices at renewable energy facilities is the first step to identifying the commonly used strategies and patterns used when mitigation is implemented. Here, the authors review the frequency with which mitigation practices are reported among different renewable energy facilities. For the purpose of this report, the authors defined mitigation as management practices to offset the effects of habitat loss and incidental take (that is, unintentional injury or death) to wildlife populations resulting from the project construction or operation (Wolfe et al. 2012; Northrup and Wittemyer 2013; Marques et al. 2014). Specifically, the analysis focuses on the following objectives: (1) identify the type and frequency of mitigation practices implemented and reported at solar and wind energy facilities within California and nationally; and (2) determine if these mitigation practices differ between energy technology (that is, solar vs. wind). The objective of the study to measure the effectiveness of mitigation strategies in reducing fatalities or habitat loss was not achievable because of the lack of data in the few reports available to the authors.

Methods

Literature Search

The authors used the same literature search as described in Chapter 2. Exceptions were that the geographic area of interest was the continental United States and Canada (because the number of reports on mitigation in California was so small, facilities from throughout North America were considered), and that the search term "mitigation" was included in searches, as were terms related to mitigation practices (for example, "cut-in speed," "evaporation pond netting"). The authors used reports from multiple provinces in Canada, all available through a public GoogleDrive (https://drive.google.com/drive/folders/0B24A4SH_cewXV0VhTENxTGp3LVk).

Data Organization and Analyses

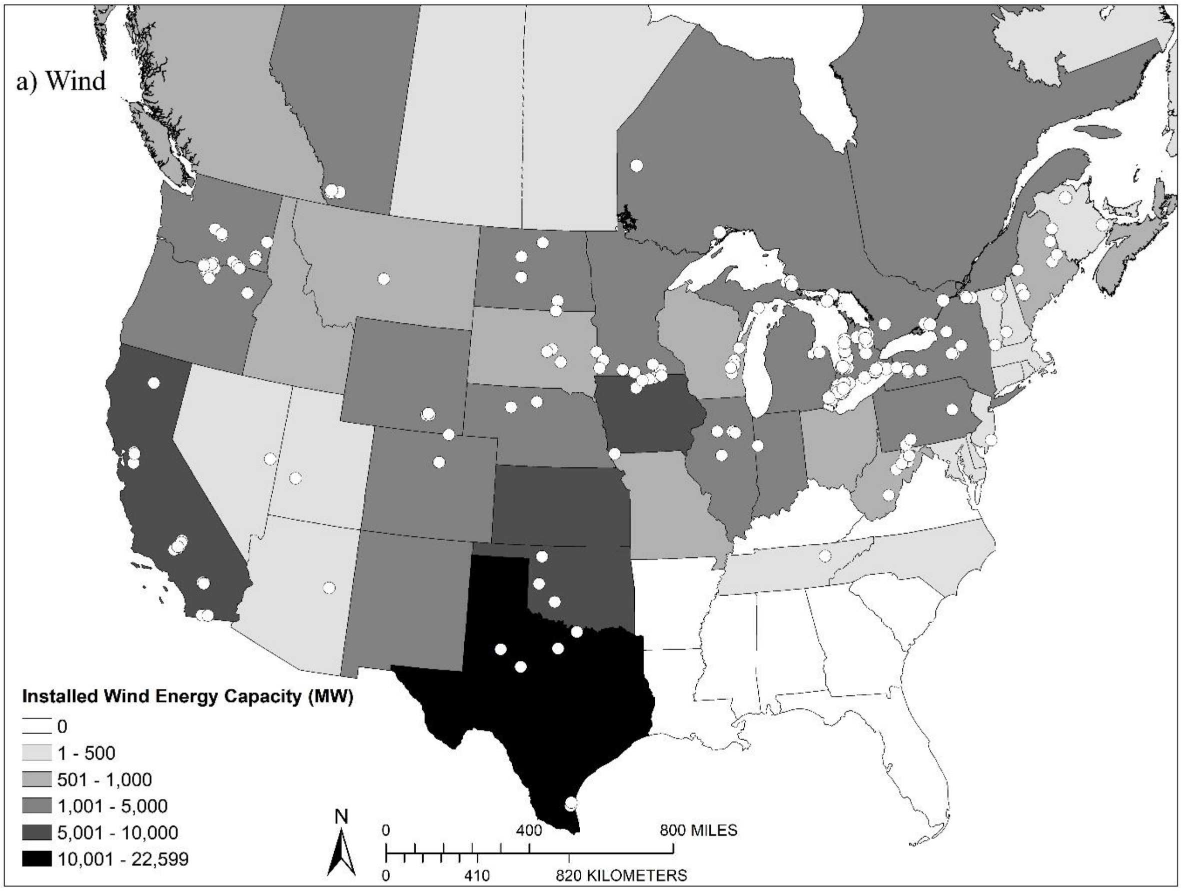
In general, the rules for data organization and naming conventions were similar to those in Chapter 2, with the following exception: The authors extracted from each document information about the renewable energy technology used at each facility (for example, wind, photo-voltaic solar, solar trough, power tower), data collection during the construction phase, and information regarding the specific type of mitigation practices implemented or survey data collected (for example, fatality, carcass, or wildlife use surveys). Additionally, if monitoring or mitigation practices were taxa or species-specific, the authors recorded the focal taxon or species (for example, common raven [*Corvus corax*]).

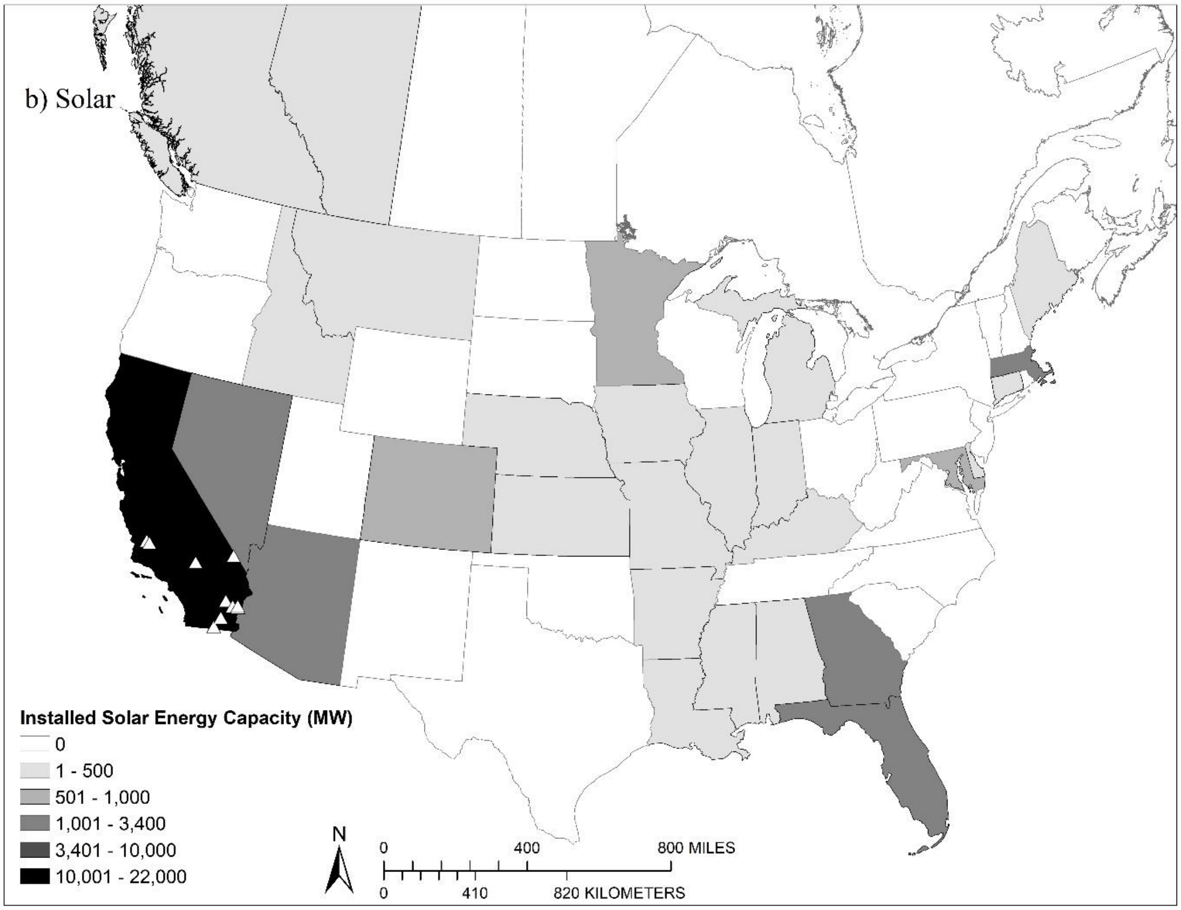
To assess the frequency of mitigation efforts, the authors summarized report data by facility and construction phase and identified the presence and type of mitigation methods across facilities and years.

Results

The authors compiled information in 632 reports on activities at renewable energy facilities. These came from 231 facilities in 31 states and provinces (Figure 6). Forty-eight reports contained data that temporally overlapped with those in other reports and were removed from subsequent analysis. The authors excluded 17 additional reports from 11 facilities that were never constructed and 28 reports from 15 facilities where construction was not yet completed or the facility did not yet have post-construction or mitigation data available. Finally, they also excluded an additional 118 citation-only records and summary documents with no information about mitigation practices at facilities. After these exclusions, the authors were left with a final dataset for analysis that contained 421 reports from 171 facilities (161 wind; 10 solar). This total included 136 unique reports from 30 California facilities (Figure 7).

Figure 6: Locations of Renewable Energy Facilities by Type Included in Mitigation Assessments

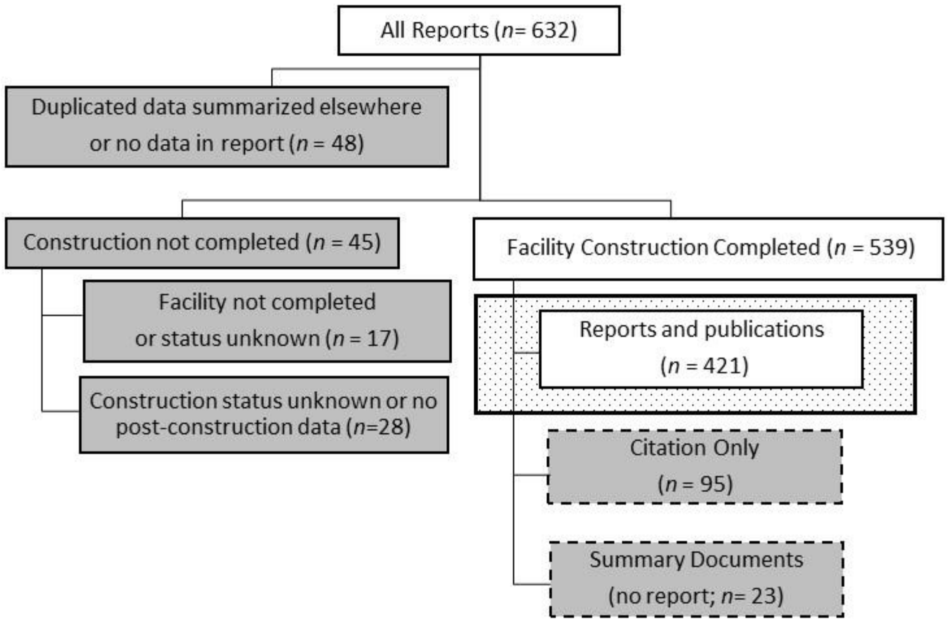




Locations of a) wind (white circles) and b) solar (white triangles) energy facilities used to assess mitigation at renewable energy facilities. Also shown is the total installed energy capacity by state of wind and solar renewable energy facilities, respectively, as of 2017.

Source: U.S. Geological Survey

Figure 7: Number of Mitigation Reports from Renewable Energy Facilities

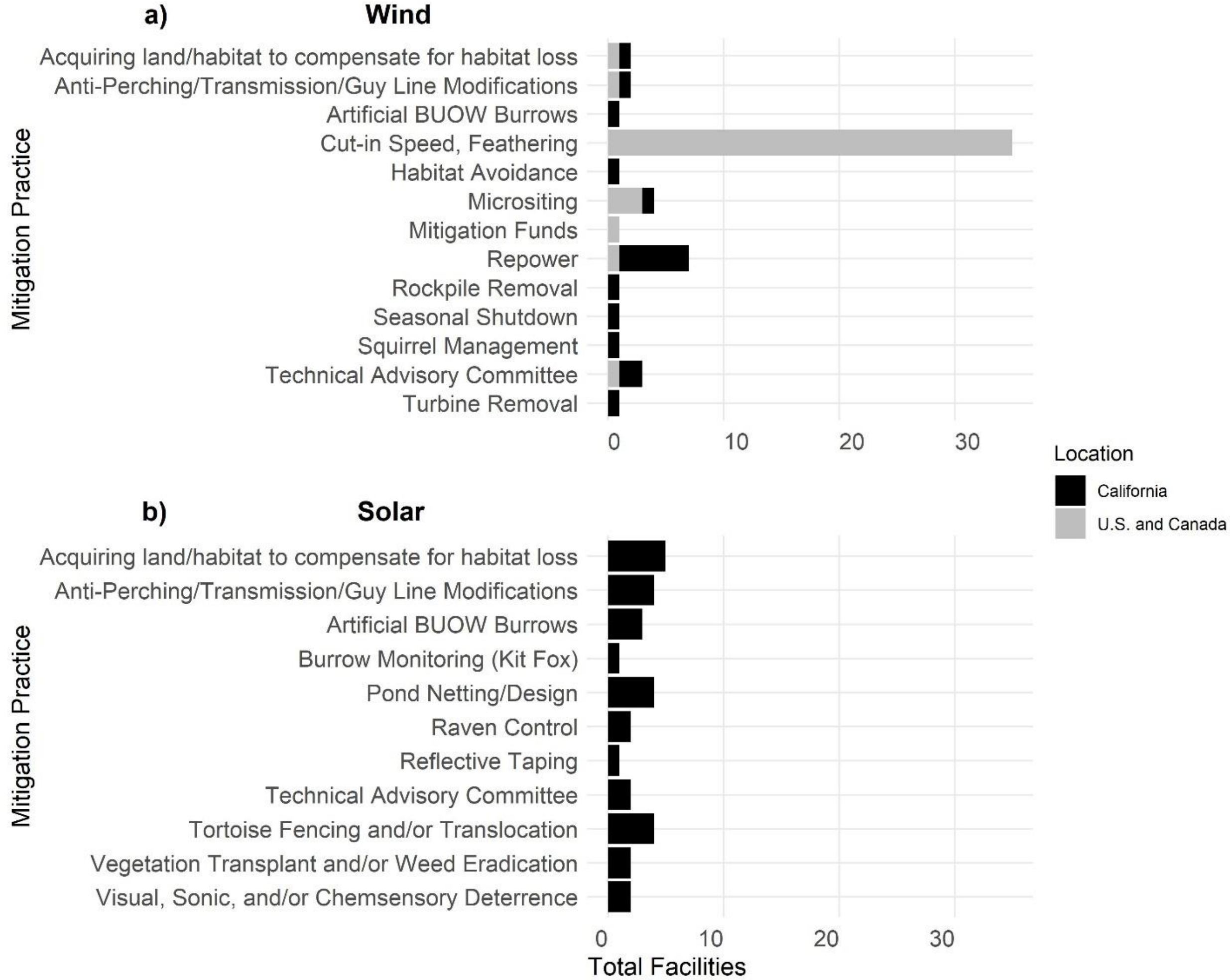


Number of reports on mitigation at renewable energy facilities. Categories of reports in dark gray boxes (left) were not included in analyses to assess mitigation practices at renewable energy facilities reported in this study. Categories of reports in white boxes were included in this study.

Source: U.S. Geological Survey

The authors documented 20 mitigation practices that were implemented at 59 facilities across the United States and Canada (*n* = 123 reports; Figure 8). In general, the mitigation practices used differed by renewable energy type.

Figure 8: Mitigation Practices at Renewable Energy Facilities



Types and numbers of mitigation practices applied at a) wind and b) solar renewable energy facilities in California (black) and the remainder of the contiguous United States and Canada (gray) during 1981–2016. BUOW = burrowing owl.

Source: U.S. Geological Survey

Wind facilities often modified turbine operations and technologies to reduce wildlife-turbine collisions, although specific practices varied by location and focal taxa. Twenty-two percent of wind facilities (*n* = 35 of 161 facilities, all outside of California) mitigated for bat fatalities by altering the cut-in speed (that is, wind speed when blades begin to turn) or feathering blades to restrict turbine operations in low wind conditions. Conversely, wind facilities in California rarely mitigated for bats and instead focused on mitigation practices including repowering, prey species management, and turbine micrositing. Generally, these approaches were used because of their expected benefits for avian species (particularly raptors), including golden eagles and burrowing owls.

Mitigation practices at solar facilities were different than those at wind facilities. All solar facilities were in California and 7 out of 10 reported mitigation. The practices employed emphasized wildlife deterrence (for example, netting over evaporation ponds, antiperching devices, reflective taping) and compensatory mitigation to offset habitat alteration and loss due to site construction by purchasing or protecting land outside the facility footprint (for example, mitigation properties; Figure 8).

Although the authors obtained information on which facilities proposed acquisitions/easements and, in some cases, whether facilities actually performed these activities, they found almost no information on the location of these activities. Thus, the authors were unable to produce maps showing the locations of compensatory mitigation land acquisitions/easements performed by or on behalf of renewable energy facilities in California.

Discussion

The authors' analysis is, to their knowledge, the only comparison of publicly available reports on mitigation activities at renewable energy facilities in California and North America. However, a number of caveats must be considered when interpreting these results. For example, the number of facilities attempting mitigation is likely greater than the results suggest because the dataset contains only a subset of all reports prepared at energy facilities. Many reports were unavailable because they were considered confidential. Additionally, in spite of the relatively large sample size (Figure 6), the authors did not acquire reports for every facility or every state or province with active renewable energy facilities. Finally, the dataset is not randomly sampled from all possible facilities and therefore it cannot be considered a fully representative sample of the United States and Canada. In spite of these limitations, there are a number of conclusions the authors can draw about mitigation in California and North America.

This survey illustrated that many of the mitigation practices used at renewable energy facilities were specific to the type of renewable energy technology being evaluated. For example, mitigation practices aimed at controlling wind turbine fatalities were mostly focused on reducing collisions with volant species. Practices in California emphasized raptors and other large avian species, likely due to the more than 30-year history of raptor fatalities at wind facilities such as APWRA (California Energy Commission 1989; Hunt 2002; ICF International 2016). Mitigation efforts at older wind facilities have focused on repowering by replacing the original lattice-style turbines with fewer, larger monopole turbines with slower-spinning blades that maintain overall energy production but are thought to reduce risk to birds (California Energy Commission and California Department of Fish and Game 2007; Arnett and May 2016). That said, while they are presented as mitigation by some who implement these approaches, not all agencies consider them suitable for meeting legal mitigation requirements.

The lack of mitigation practices directed at bats in California was unexpected given that many facilities elsewhere focused on cut-in speed and feathering of blades to restrict turbine blade movement (Baerwald et al. 2009; Arnett et al. 2011; Arnett and Baerwald 2013). In fact, only one unnamed wind facility within USFWS Region 8 (California and Nevada) implemented mitigation for bats (Arnett et al. 2013). The lack of mitigation for bats may be driven by perceptions of prime conservation concerns in California. Within the state, raptor deaths are a known issue, whereas fatality searches at wind facilities in California historically found few bat carcasses (ICF International 2016; Ventus Environmental Solutions 2016). This may stem from the use of human observers that are unlikely to detect a high proportion of small-bodied bat carcasses. In recent years, searches using dogs to locate wildlife carcasses increased the number of bat carcasses found at renewable energy facilities in other states (Arnett 2006; Paula et al. 2011). Expanded use of dog searches at facilities in California will improve existing knowledge of bat fatalities and help assess the potential for taxa-appropriate mitigation practices (Arnett and May 2016; Reyes et al. 2016).

Mitigation practices at solar facilities were often aimed at alleviating attraction to solar panels or drowning deaths in evaporation ponds (Figure 8). Additional practices during facility construction targeted terrestrial species with limited mobility (for example, cacti, desert tortoise) by excluding those species from the facility footprint (for example, exclusion fencing for tortoises) or relocating animals to alternative locations outside the facility (for example, burrowing owl, kit fox, desert tortoise).

Because most utility-scale solar facilities are recent developments (less than 10 years old), there are limited data to determine how fatality risk at solar facilities varies by technology type (for example, photovoltaic panels vs. concentrated solar power towers) or among solar components such as photovoltaic panels vs. evaporation ponds, facility fencing, or transmission lines (Argonne National Laboratory and National Renewable Energy Laboratory 2015a). Continued fatality and wildlife use monitoring at solar facilities may guide current and future mitigation practices or identify additional species in need of mitigation assistance (Jenkins et al. 2015; Huso, Dietsch, and Nicolai 2016).

Addressing Data Limitations

Data availability constrained the survey results. There were many reasons why the authors could not access all potential data for this study. Reporting requirements and report accessibility varied among countries, states, and counties and rarely did a single entity serve as an all-purpose data depository for any given locality. Additionally, facility owners rarely had identical perspectives on data accessibility. This is especially true because regulatory agencies generally have limited monitoring or reporting oversight for privately owned facilities on private land, unless specifically outlined in state regulations, federal guidelines, or power purchase agreements. As a result, data from many facilities on private properties or developed by private companies were either not collected or not publicly accessible and, thus, not included in the study.

Some reports containing data collected in the last five years were not available because time lags exist between data collection and report publication. The frequency of these lags appears to vary by energy type. For example, solar thermal energy facilities larger than 50 megawatt in capacity in California are licensed by the California Energy Commission. The Energy Commission creates facility-specific conditions of certification for the project owner and requires reports be published on their website at quarterly or annual intervals (California Energy Commission 2010). In contrast, no single state agency licenses California wind facilities, and counties within the state vary in their reporting requirements and data accessibility. Additionally, most wind facilities generate annual or multiyear, rather than quarterly, reports. This means that reporting is more frequent at solar than wind facilities, and this may explain the relative lack of reports for wind facilities in recent years. These gaps in accessibility are illustrated by the 118 citation-only records and summary documents in the dataset (these are records for reports the authors knew about but were unable to access).

A mechanism to address this data availability issue may be through voluntary submission of monitoring records to a central repository. Although voluntarily submitted data may not be completely representative of the overall population, a publicly available repository for data collected at renewable energy facilities would have tremendous benefit. These benefits would be not only for conservation scientists and wildlife managers, but also for energy developers, who frequently share the common goal of understanding renewable energy impacts to wildlife and building cost-effective and generalizable mitigation protocols. The American Wind Wildlife Institute (AWWI), has taken steps in this regard by compiling a public document library including peer-reviewed literature and nonpublished reports from multiple wind energy facilities in North America (AWWI 2017).

Although the authors cannot statistically analyze these datasets, a cursory examination suggests a lack of (reported) mitigation practices at many facilities. However, given that most of these reports were focused on pre- and post-construction wildlife use and fatality monitoring studies, it is possible that the authors of these reports were not required or inclined to include mitigation-specific results or practices in their reports. Further information on mitigation practices may be available in other documents compiled for a given facility (such as pre-construction monitoring plans) that were unavailable in the literature search.

CHAPTER 4: Application of Isoscapes to Determine Geographic Origin of Terrestrial Wildlife for Conservation and Management in California

Introduction to Using Isoscapes to Infer Geographic Origin

The most abundant elements in living organisms (hydrogen, carbon, nitrogen, and oxygen) have naturally occurring stable isotopes with additional neutrons (^{2}H, ^{13}C, ^{15}N, ^{17}O, ^{18}O) that tend to accumulate in tissues differentially through space and time relative to forms with fewer neutrons (^{1}H, ^{12}C, ^{14}N, ^{16}O). Such variation in the stable isotope ratios of these elements provides data integral to quantifying spatiotemporal characteristics of natural earth systems. Spatial isotope distributions across landscapes, or isoscapes, can be generated from predictive models of isotopic values by interpolating measurements from a limited number of points to a more extensive geographic range (Bowen 2010). Consequently, over the last decade, isoscapes have become a fundamental tool to address large-scale questions about the movement of organisms (Bowen et al. 2009), such as population-level impacts of renewable energy.

For many species of migratory wildlife, including birds, bats, and insects, stable isotope data, in the context of their associated isoscapes, can provide ecological insight into year-round habitat use and connectivity (Hobson, Wassenaar, and Taylor 1999; Cryan et al. 2004; Hobson 2005, 2011; Hobson et al. 2012a; Knick et al. 2014). Such data may also be useful in more applied settings when movement of individuals and connectivity through the annual cycle presents challenges for conservation and management programs (Webster et al. 2002; Martin et al. 2007; Runge et al. 2014). Animal movements are often tracked with labor- and cost-intensive telemetry or data logging systems. However, when using an intrinsic marker such as stable isotopes, recovering tagged individuals is not necessary (Bridge et al. 2013), and the expense is significantly less than that incurred with remote tracking technologies. The primary tradeoff in using stable isotopes in comparison with extrinsic markers is typically a reduction in geographic precision with the former. Nevertheless, the stable isotope approach can yield valuable information that is highly relevant to conservation and management.

To date, the most commonly used stable isotope approach to track terrestrial wildlife movement is based on environmental water isotope composition. In particular, hydrogen and oxygen stable isotope values ($\delta^{2}H$ and $\delta^{18}O$) in precipitation vary considerably across continental scales due to preferential rainout of the isotopically heavier water molecules across continental and elevational gradients (Dansgaard 1964). The local environmental isotope signal is assimilated into seasonally grown tissue via diet and drinking water (Hobson and Wassenaar 1997, 2008), and the δ^2H values of animal tissues correlate with the δ^2H values of local meteoric water (Hobson, Atwell, and Wassenaar 1999). Thus, δ^2H values of tissues that are metabolically inert after synthesis, such as fur, feathers, claws, and exoskeleton, can be used to retrospectively estimate where they grew.

Over the last two decades, there have been many applications of stable isotope analyses to understanding ecology of animal migration. Much of this research has focused on the migratory connectivity of populations, information that may occasionally inform conservation. That said, research in direct support of specific conservation and management goals is emerging, and the field of stable isotope ecology is poised to make rapid advances of immense relevance to conservation biology. In California, it is important to understand the origins of wildlife killed at renewable energy facilities. Thus, the purpose of this chapter is to provide (1) a guide to the analytical considerations and geographic assignment model process; and (2) examples of conservation problems and isotopic solutions that explore the effects of different conditions on assignment outcomes and that identify potential strengths and limitations to the approach that will be used for geographic assignment of individuals killed at renewable facilities.

Applications to Animal Ecology and Conservation Questions

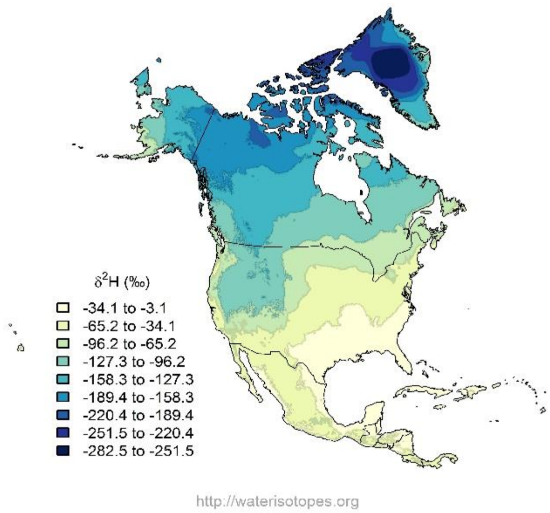
Stable isotopes have a long history of use to examine more traditional components of an organism's niche, such as through revealing dietary composition or habitat use (mainly via carbon and nitrogen isotope analysis), which can be informative for wildlife conservation and management (Newsome et al. 2007, 2012). Species with complex life histories present challenges to understanding population dynamics across spatial and temporal scales (Webster et al. 2002). Isotopic approaches can be used to determine origin in addressing conservation, such as connections between breeding and nonbreeding seasons, migratory status of an individual, and assessing geographic structure of individuals sampled at the same location.

Study Considerations

Data Sources

Several types of isoscapes have potential for assigning geographic origin of wildlife. The most commonly used isoscapes are derived from δ^2H and $\delta^{18}O$ precipitation stable isotope data (Figure 9), available through the Global Network of Isotopes in Precipitation (IAEA/WMO 2011). Other types of isoscapes that map soil water (Pekarsky et al. 2015), groundwater (Hobson et al. 2009a), or plant water isotopic composition (Bowen et al. 2018) could represent a more temporally integrated signal of water that is transferred through the food web. However, there has been limited exploration to date of the utility of such alternatives for geographic assignment.

Figure 9: Precipitation Isoscape



Example of precipitation isoscape: mean annual δ^2H values of precipitation in North America.

Source: Bowen and Revenaugh 2003; http://waterisotopes.org

Spatially distributed measurements of known-origin individuals can also be used to create tissue-based isoscapes without the need to characterize baseline processes that contribute to geospatial patterns in isotopic ratios of precipitation (for example, Hobson, Wassenaar, and Taylor 1999; Hobson et al. 2009a; Gutiérrez-Expósito et al. 2015). Organism-specific isoscapes may more accurately characterize the geospatial distribution of the isotopic composition of a species than would baseline-derived isoscapes. However, the application of these isoscapes is limited to the species for which they are developed, and it can be difficult to obtain sufficient numbers of known-origin samples across a large enough spatial range to construct the isoscape. This may be especially true in a conservation setting where many different and sometimes rare species are affected by anthropogenic processes (for example, fatalities of birds and bats at renewable-energy facilities).

Geographic assignment of terrestrial wildlife generally is achieved with δ^2H rather than δ^{18}O isoscapes. This is likely because the relationship between tissue and precipitation δ^{18}O values is weaker than that for δ^2H values (Hobson et al. 2004; Hobson and Koehler 2015). Although both vary geographically, the breakdown of the meteoric relationship in animal tissues may be a result of metabolic processes as animals integrate these elements (Vander Zanden et al. 2016). Nevertheless, hydrogen and oxygen each have distinct advantages and disadvantages for the analysis of the stable isotope composition of organic materials. Hydrogen inputs into an organism consist of diet and drinking water, whereas oxygen has a third input (inhaled atmospheric O_2), and there may be differing and separate controls required to interpret tissue δ^2H and $\delta^{18}O$ values. A more detailed treatment of these issues is in Vander Zanden et al. (2018).

Tissue Type

A consideration in selecting a tissue for isotope analysis is the time period over which the environmental isotopic signal is integrated into the organism's tissue. Metabolically active tissues such as blood and skin integrate isotopic composition in diet or air over a limited period of time. The integration period, or isotopic turnover time, generally increases with body mass and is longer for tissues such as muscle and blood than for plasma and internal organs (M.J. Vander Zanden et al. 2015). In contrast, keratin and chitin-based inert tissues such as fur, feathers, claw, and exoskeleton have distinct temporal isotopic dynamics; they do not change after synthesis, and they reflect the discrete time interval during which the tissue was grown (Hobson and Wassenaar 2008). One challenge with estimating the time period represented in a tissue sample is that even if the growth period of a tissue is well-characterized, the time period over which the organism's dietary items would have integrated the environmental signal at lower trophic levels is difficult to constrain (Coulton et al. 2009; Bortolotti, Clark, and Wassenaar 2013; Vander Zanden et al. 2014a). Additionally, migratory organisms may not always be at isotopic equilibrium with the local environmental signal at the time of tissue growth and may instead rely on stored nutrients that were integrated prior to the period of tissue synthesis (Wunder, Jehl, and Stricker 2012). Nevertheless, understanding the timing of tissue synthesis is essential to inform what portion of an organism's annual cycle is represented by the δ^2H values of any particular sample.

For species such as bats and birds that undergo regular molts of inert tissue (for example, fur, feathers), characterizing the molting time frame is crucial if molted tissue is to be used in isotopic analysis. Temperate bird species typically molt at specific times during the annual cycles of breeding and migration, and many species undergo a complete replacement of feathers (both flight and body feathers) over the course of a year (Pyle 2008). This molt usually occurs after breeding while still on or near the breeding grounds, and thus, birds sampled during migration or on the wintering grounds can be assigned to a breeding origin. However, molt patterns can be complex and vary greatly among species (Howell et al. 2003). For example, there may also be a second annual molt of some or all of the body plumage (and sometimes the flight feathers) in the winter or spring (Pyle 2008). Other species molt during migration, which means stable isotopes in feathers cannot be used to connect end points of migration (Pillar et al. 2016). That said, for species with gradual feather replacement, sampling multiple feathers in different body regions that represent molt throughout the year may provide information at different periods of the life cycle (Robillard et al. 2017).

Temperate bat species usually undergo an annual molt during the summer months (Quay 1970; Cryan et al. 2004; Fraser et al. 2012). Thus, δ^2H values of hair may be a viable method for inferring the summering grounds of migratory bats captured at other times of the year (Britzke et al. 2009; Fraser et al. 2012; Popa-Lisseanu et al. 2012; Sullivan et al. 2012; Cryan, Stricker, and Wunder 2014; Pylant et al. 2016). Some bat species are thought to breed on or near their summering grounds (for example, Popa-Lisseanu et al. 2012), whereas others breed during fall migration or on their wintering grounds (Shump and Shump 1982a, b; Cryan 2003). As with birds, the applicability of δ^2H data for inferring the breeding grounds of temperate bats sampled during migration or on their wintering grounds may be species-specific. In addition, systematic variation between back and belly fur has been detected in two species of bats, and thus, a standardized sampling protocol should be considered, especially if pooling data from multiple sources (Fraser et al. 2015).

Conducting Geographic Assignments with a Probabilistic Approach

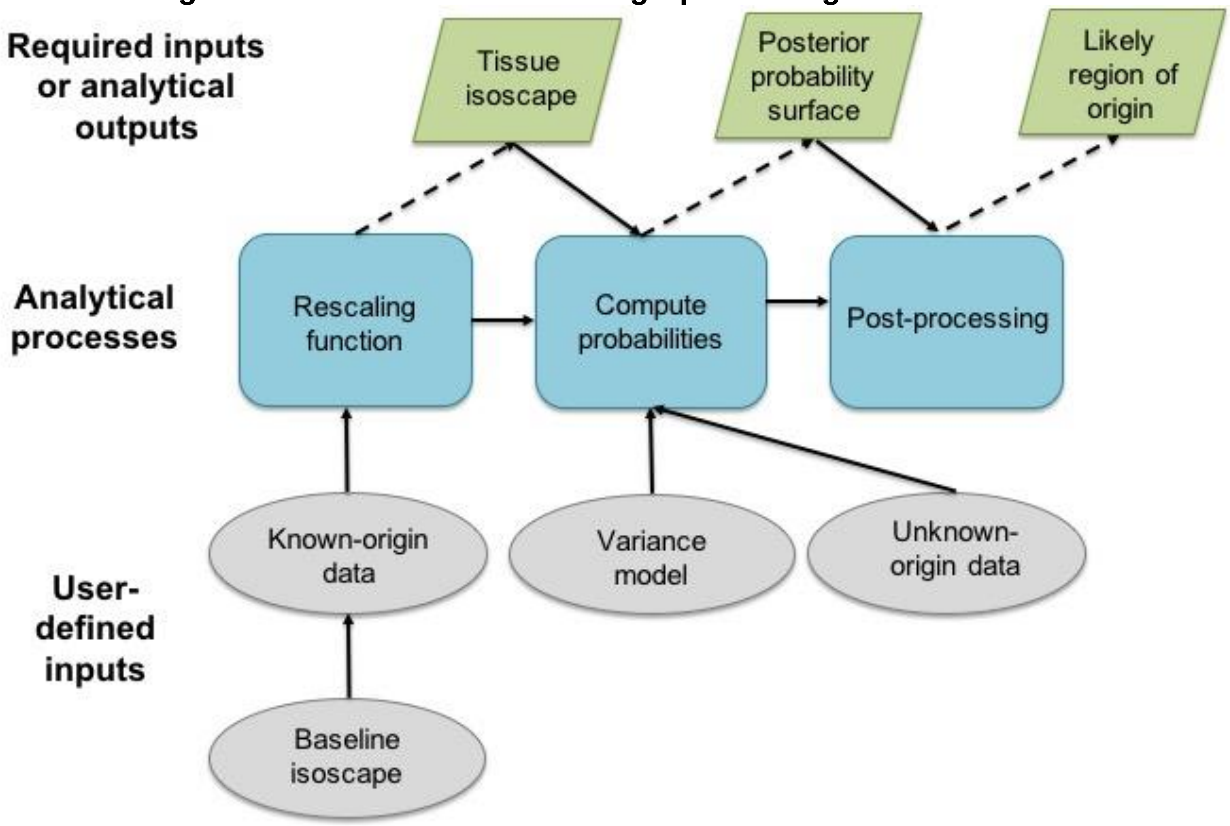
Assignment models to determine geographic origin can be divided into two general types (Wunder 2012). These are either nominal or continuous, representing cases in which individuals are assigned either to a limited number of groups or to a continuous but defined geographic range. Nominal assignment methods require *a priori* and isotopically distinct groupings that often are geographic in nature (Wunder and Norris 2008; Miller et al. 2012; Vander Zanden et al. 2014b; Brennan et al. 2015). Application of the nominal approach and incorporation of uncertainty into these models has been addressed in previous reviews (Wunder and Norris 2008; Wunder 2012); thus, the following section focuses on the steps for using continuous assignment, with examples to illustrate this approach.

Assigning geographic origin to a sample requires four steps:

1) Selecting a baseline isoscape
2) Defining a rescaling function to relate tissue isotope values to those in the baseline isoscape
3) Constructing a variance model structure to define the principle variance sources in the tissue and isoscape distributions
4) Using a Bayesian framework to determine the conditional probabilities of the sample originating over all possible locations within the geographic range

Researchers may choose to use the posterior probability distributions in a fifth step to conduct post-processing analyses to define likely regions of origin or to summarize across multiple individuals. Each of these steps is discussed below briefly and diagrammed in a flow chart (Figure 10); for a more detailed treatment, see Vander Zanden et al. (2018).

Figure 10: Flowchart of the Geographic Assignment Process



Flow-chart outlining the geographic assignment process using isoscapes with required inputs or analytical outputs (green parallelograms); analytical process steps (blue rectangles); and user-defined inputs (gray ovals). Variance models, which are described in detail in the text, can include analytical, intra-individual, inter-individual, and baseline isoscape variance, or other sources defined by the user. Dashed lines indicate outputs, and solid lines indicate inputs.

Source: U.S. Geological Survey

Baseline Isoscape

The first step in the assignment process is to select a baseline isoscape. When considering precipitation, these isoscapes may integrate long-term isotopic data across the whole year (so called, *mean-annual*, hereafter *MA*), within the *growing season* (hereafter *GS*), or at other intervals defined by the user (Bowen and Revenaugh 2003; Bowen, Wassenaar, and Hobson 2005; Terzer et al. 2013; Bowen et al. 2014, 2018; Waterisotopes.org 2017). GS isoscapes are used more frequently than MA isoscapes in migratory applications, as they are thought to better represent the timing of H isotopic flow into primary food webs that contribute to animal diet and tissue growth (Hobson et al. 2012b). Both the MA and GS isoscapes are calculated as amount-weighted, long-term means over several decades, whereas organismal tissues are synthesized and integrate an environmental signal over a much shorter time frame that may deviate from the long-term means.

Rescaling Function

The next and possibly most crucial step to evaluate origin in a continuous framework is to define the rescaling function to relate tissue values to those in the baseline isoscape. Such relationships typically take the form of a linear regression, termed a *rescaling function*, because the relationship between tissue and precipitation δ^2H values is often not 1:1. Rescaling functions rely on (1) values from a baseline isoscape (see above); and (2) isotopic data from known-origin samples collected across the geographic, temporal, and isotopic ranges of interest for the study species. Establishing a calibration dataset can be logistically challenging and also costly, and as a consequence, relatively few studies have systematically obtained known-origin samples to generate a rescaling function. While it is preferable to use known-origin samples of the same species and age as the species of interest, this is not always possible. In such cases, previously published rescaling functions are often re-used, and these regressions have been calibrated in single species and multiple species together (Bowen, Wassenaar, and Hobson 2005; Lott and Smith 2006; Hobson et al. 2012b).

Variance Model

The next step of the assignment process is to incorporate the sources of variance that contribute to the analysis and interpretation of the stable isotope data. Sources of variance that are often considered include analytical (or measurement) variation, intra-individual variation, inter-individual (or within-population) variation, and variation in the baseline isoscapes (generated during the spatial interpolation process). Analytical error is usually described by the variance of isotopic values of reference materials analyzed with the unknown samples on the isotope ratio mass spectrometer (Jardine and Cunjak 2005; Bond and Hobson 2012).

Intra-individual variance in isotope values may be a result of isotopic heterogeneity within a tissue type of an organism, whereas inter-individual variance may originate from differences in diet, behavior, and physiology of individuals at the same location (Powell and Hobson 2006; Wassenaar and Hobson 2006; Smith, Donohue, and Dufty 2008; Fraser et al. 2011; Hobson et al. 2012b; Wunder, Jehl, and Stricker 2012). The extent of intra- and inter-individual variation appears species-specific, with less influence from other factors such as nesting substrate and diet composition (Nordell et al. 2016). Finally, when geostatistical models are used to generate isoscapes, the uncertainty in the predicted surface is related to the spatial distribution of the data. Regardless of the source of the baseline isoscape, an error surface should be incorporated into data interpretation. When these sources of variance (and any others) are assumed to be independent, they can be summed in a combined error term that is part of the expected distribution of feather values for a location.

Calculation of Conditional Probabilities

In the conditional assignment process, the likelihood that the location is the origin is evaluated given the measured δ^2H tissue values. For each pixel of the continuous surface, Bayes' rule is used. The prior probability can take multiple forms but most often is uniformly distributed across a defined range. If the prior probability consists of patchy species abundance data, the abundance data may overwhelm the contribution of the isotope data to assignments, and down-weighting the abundance data may maximize the assignment efficacy (Rushing, Marra, and Studds 2017). Finally, the posterior probabilities are rescaled to sum to one across all possible locations in the output raster.

There are a number of tools that can be used to calculate posterior probability surfaces. First, IsoMAP allows for prediction of origin to precipitation isoscapes that have been generated within the online workspace, and these products can be shared through the web interface. More complete guidance for conducting assignments in IsoMAP has been provided elsewhere (Bowen et al. 2014). Because of the complexities of using IsoMAP, many studies (for example, Hobson et al. 2013; Procházka et al. 2013; Guillemain et al. 2014; Vander Zanden et al. 2014a; Holberton et al. 2015) have used the software R (R Core Team 2016) and their own code to generate posterior probability distributions for multiple individuals. R code and packages have also been developed to accomplish specialized implementations of geographic assignment models (for example, isoscatR, IsoriX, gaiah; Rundel et al. 2013; Ruegg et al. 2017; Courtiol et al. 2019).

Post-Processing

Two of the most common post-processing steps after the assignment analysis are (1) to select areas of high likelihood through the use of a threshold; and (2) to summarize the maps from multiple individuals. An odds ratio framework can evaluate the strength of support for favoring one location relative to others. Odds ratio thresholds are associated with predicted accuracy rates, which can be tested with known-origin datasets. For example, using a conservative 19:1 odds ratio threshold to designate a portion of the surface as a likely origin predicts that the true location would be contained in the selected region 95 percent of the time, and in turn, the frequently used 2:1 odds ratio (Hobson et al. 2009b; Van Wilgenburg et al. 2012; Asante et al. 2017) yields a lower predicted accuracy at a rate of 67 percent. Thresholding has also been accomplished by using a fixed proportion of the surface (Hobson et al. 2013; Guillemain et al. 2014; H. B. Vander Zanden et al. 2015; Seifert et al. 2016) or by using relativized probabilities, in which probabilities are rescaled to values between 0 and 1 by dividing by the value in the cell with the maximum probability (Vander Zanden et al. 2014a; Brennan and Schindler 2017). Alternatively, Monte Carlo simulations using known-origin data have been used to determine the minimum isopleth that contained the true location and select thresholds to establish likely areas of origin for individuals of unknown origins (Nelson et al. 2015; Pylant et al. 2016; Katzner et al. 2017).

It can be challenging to summarize population level patterns when examining the geographic origin for multiple individuals. The common method for reducing the information contained in multiple individual maps is to apply a threshold to create binary surfaces of likely vs. nonlikely origins and then sum all resulting maps. This process results in a single map representing a count or proportion of individuals that likely originated from each cell (Hobson et al. 2009b, 2015; Van Wilgenburg and Hobson 2011; Holberton et al. 2015). The problem with thresholding before summarizing multiple maps is that some of the information in the original maps is lost. In some cases, it also may be important to recognize the extremes of the ranges of origin rather than just the areas used by the majority. Another summary approach can be to cluster individuals based on similar patterns of likely origin. This process is more straightforward when geographic regions are predefined, and the region of highest probability can be deemed as the region of origin (Wunder and Norris 2008; Flockhart et al. 2017).

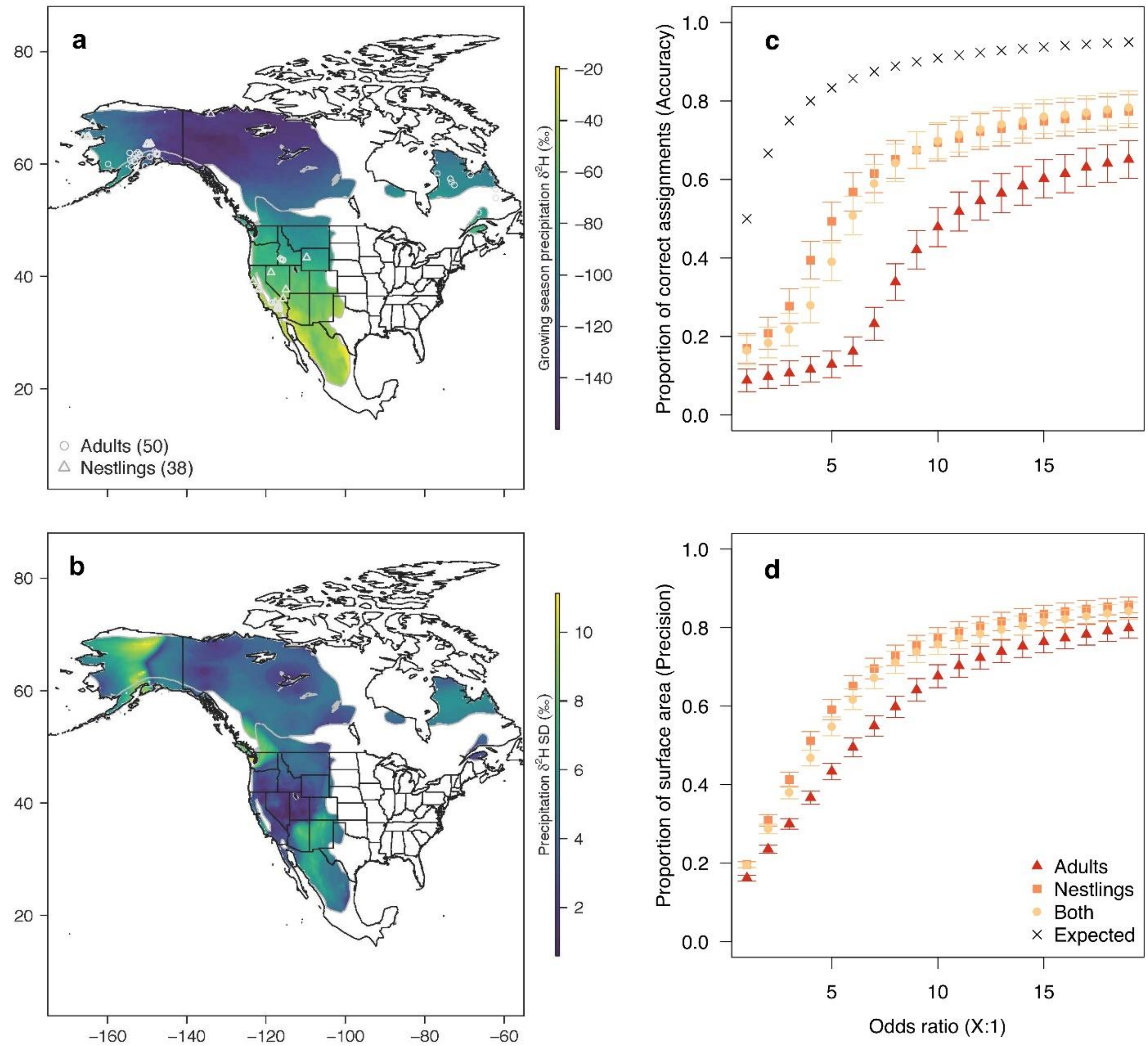
Cautions

Use of stable isotopes requires an understanding of the limitations and associated assumptions that must be made regarding the species' biology and isotopic integration. In some cases, atypical methods for using isotope data in geolocation efforts may have contributed to erroneous conclusions and misguided cautionary messages about the use of H isotopes for geographic assignment (Wittenberg, Lehnen, and Smith 2013; Warne, Proudfoot, and Crespi 2015; Briggs, Poulson, and Collopy 2017). Compared to other markers, the main drawback of geographic assignment with stable isotopes is a lack of precision, which is why the majority of studies that have used this approach are conservative in delineating origins and report findings on a broad scale (Hobson 2011). Delineating origins of animals killed at renewable energy facilities is a situation where these conservative delineations are usually appropriate.

Example Application

Decisions made during the assignment process have consequences that are relevant to wildlife conservation. As an example, the authors evaluated how far away golden eagles originated from the locations where they were collected. Accidental trauma (that is, collisions and electrocution) is an important cause of anthropogenic mortalities for this species (Franson, Sileo, and Thomas 1995; Millsap et al. 2016). Therefore, understanding the origin of individuals that have died in collisions can be important to interpret eagle population dynamics and conservation. The golden eagle dataset the authors used consists of a combination of previously published (n = 44; Nelson et al. 2015; Katzner et al. 2017) and new (n = 44) δ^2H feather values from known-origin adults (n = 50) and nestlings (n = 38) collected across North America between 2012 and 2016, as well as a single museum specimen of a nestling collected in 1884 (Figure 11a, b). Additional information regarding the collection and analysis of the feather data is available with a peer-reviewed publication stemming from this research (Vander Zanden et al. 2018).

Figure 11: Sampling Locations, Precipitation Values, Accuracy, and Precision of Assignment for Golden Eagles



Sampling locations of a) golden eagle adults (*n* = 50) and nestlings (*n* = 38) collected between 1884 and 2016 mapped on isoscapes of growing season δ^2H precipitation values; b) standard deviation of mean annual precipitation δ^2H values that were restricted to the species' breeding range; and c) mean accuracy and d) precision ± standard error of assignment to origin for golden eagles separated by life stage and combined. Odds ratios thresholds were used to select a portion of the assignment surface and evaluate whether the known origin was contained in the surface (accuracy) and what portion of the breeding range was included (precision). Expected values are the predicted accuracy using the odds ratio framework.

Source: (a) Bowen, Wassenaar, and Hobson 2005; (b) BirdLife International and Handbook of the Birds of the World 2016; (c) and (d) U.S. Geological Survey

Assignment Methods to Determine Geographic Origin

The authors used a continuous surface assignment from individuals of known origin to compare model predictions to the actual location of origin. This approach allowed evaluation of the assignment accuracy and precision using the odds ratio approach. The authors first iterated an equal division of the data 100 times to create separate calibration and validation groups. They then used the calibration data in a second level of resampling to generate 1,000 linear regressions between growing season precipitation (δ^2H_p) values (Bowen, Wassenaar, and Hobson 2005) and feather (δ^2H_f) values, accounting for variance to convert the precipitation isoscape into a feather isoscape. They assessed the accuracy and precision of the validation data in an odds ratio framework using a range of thresholds from 1:1 to 19:1 odds to delimit a region of likely origin and evaluate whether the true location was included in that area (accuracy) and calculate the portion of the total possible area that was selected (precision) at each threshold. Additional details on this process are available in Vander Zanden et al. (2018).

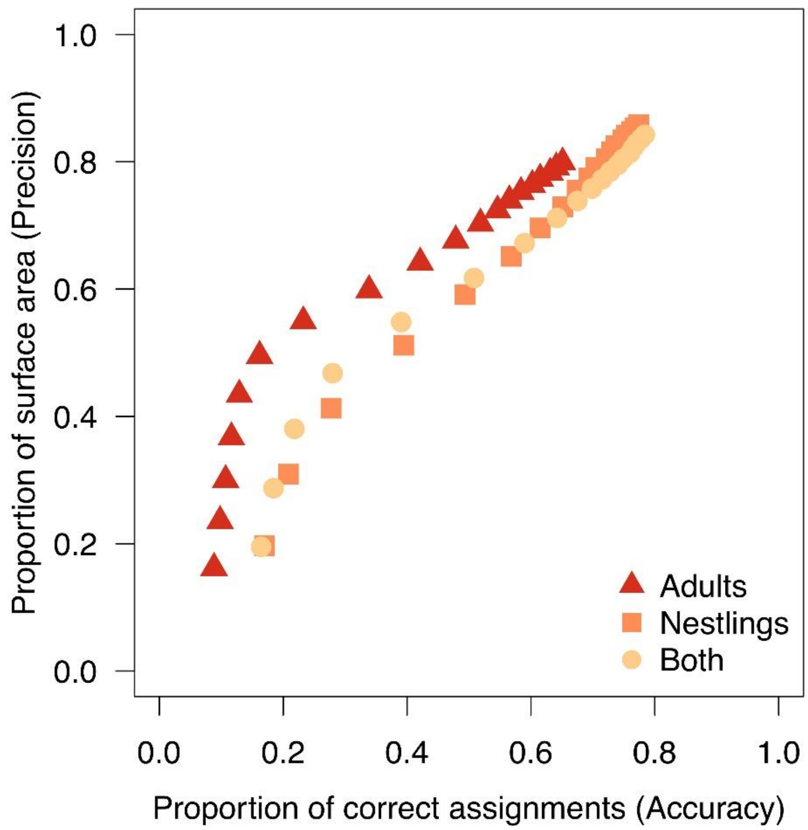
Interpreting Example Assignment Results

For the purposes of this analysis, the authors defined accuracy as the proportion of correct assignments. By using increasingly conservative odds ratio thresholds, accuracy was improved, although it began to plateau around 10:1 odds (Figure 11c). At 19:1 odds ratio, an accuracy rate of 95 percent would be expected. That said, maximum mean accuracy at the 19:1 threshold was 65 percent for adults, 77 percent for nestlings, and 78 percent for the two life stages together (Figure 11c). At the 2:1 threshold, all groups were below the predicted accuracy of 67 percent, with adults falling substantially below that.

For the purposes of this analysis, the authors defined precision as the proportion of the breeding range that was included at any given threshold in which high precision translates to selecting smaller portions of the potential range. The mean proportion of the breeding area that was included in the putative region of origin at the 19:1 odds ratio was 80 percent for adults, 86 percent for nestlings, and 84 percent for both life stages together (Figure 11d). At the 2:1 threshold, the area included was 23 percent for adults, 31 percent for nestlings, and 29 percent for both life stages together.

These results illustrate an accuracy-precision trade-off that has been previously identified in selecting thresholds (Vander Zanden et al. 2014a; Trueman, MacKenzie, and St John Glew 2017). More specifically, a higher accuracy results in a lower precision; more of the possible area is included in the putative region of origin (Figure 12). Plotting these relationships can aid managers in weighing decisions about how to delimit likely regions of origin, and the consequences of making interpretations incorrectly may dictate the level of accuracy needed.

Figure 12: Relationship Between Accuracy and Precision



Relationship between accuracy and precision in golden eagles at increasing odds ratios from 1:1 to 1:19.

Source: U.S. Geological Survey

How Far Away Did Individuals Originate?

Anthropogenic interactions and wildlife fatalities may have population ramifications that extend beyond the site of occurrence, particularly for migratory species. The authors explored a summarization metric in an attempt to distill how far from the capture site an individual may have originated. This can be especially important if, for example, wildlife are killed by human activities such as renewable energy, and it is important to understand the catchment area from which those individuals are drawn.

Several approaches have been used to quantify the distance between the origin and capture sites. These include calculating the distance to the grid cell with the highest relative posterior probability value, to a boundary of a region of likely origin, to the nearest location with a relevant δ^2H_p value, or to a centroid of a region of likely origin. However, there has been little exploration as to how these different approaches to distillation of information affect the overall interpretation of the data.

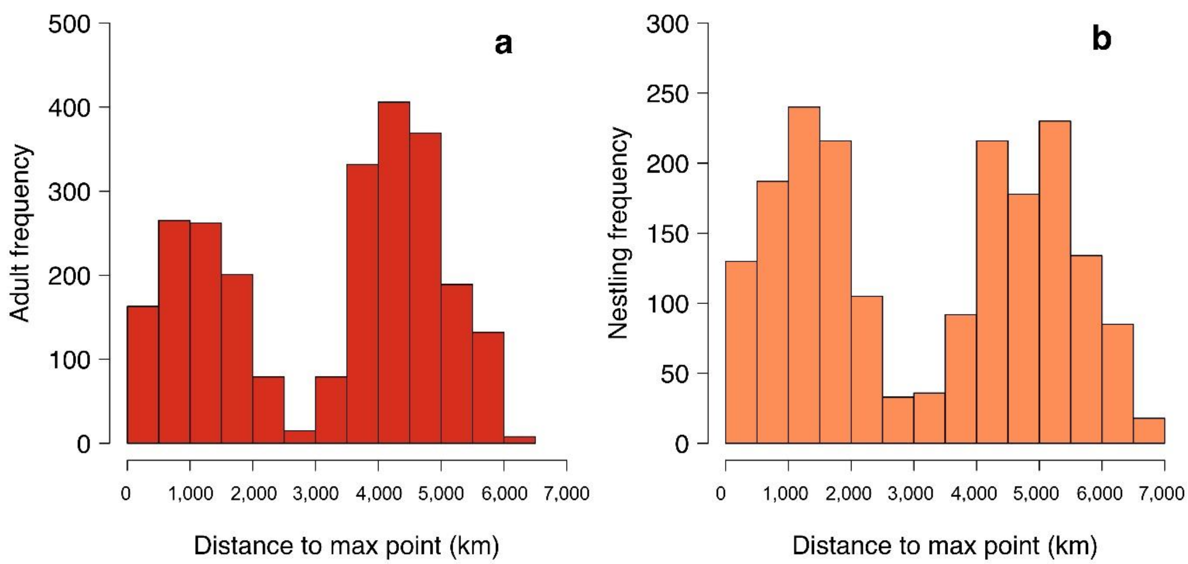
Distance Calculation

Following the same assignment procedure as used in the example above, the authors made an additional calculation to measure the distance from the known location of origin to the pixel of maximum likelihood on the posterior probability surface. The expectation is that the distance metric should be small and close to zero when the assignment accuracy is high. When using samples from unknown individuals, the calculation would consist of measuring the distance from the capture location to the maximum posterior probability pixel, and this would reflect variability in the overall migration distance among individuals.

Interpreting Distance Results

As a result of the known-origin status of the samples, the distance metric reveals how far the maximum probability point deviates from the point of known origin. The distribution of distances is large for golden eagles, likely because of the large geographic range of this species (Figure 13). The bimodal distribution indicates that the maximum probability point is very far from the known origin location in the majority of cases, often 3,000 kilometers (km) to 6,000 km (Figure 13).

Figure 13: Distribution of Distances for Golden Eagles



The distribution of distances between the capture site and the maximum grid cell on the posterior probability surface for golden eagle a) adults and b) nestlings. The frequencies differ between life stages and represent half of the dataset times 100 iterations.

Source: U.S. Geological Survey

Examination of assignment maps for adult golden eagles suggested that the points of maximum probability for many of the adults originating in Alaska corresponded to isotopically similar areas in Canada. This likely contributed to the bimodal distribution of the distance metric (from the capture location to the grid cell on the posterior probability surface with the highest value) in adults (Figure 13a). Therefore, the distance metric may have been an oversimplification to distill the surface to one point and using the minimum distance to an edge of the putative region of origin could have been more accurate.

Recommendations and Future Horizons

The use of isoscapes for geolocating migratory animals has considerable potential for the field of wildlife conservation and management and for understanding the effects to wildlife of fatalities at renewable energy facilities. Nevertheless, the geographic assignment process requires a number of inputs with associated assumptions and decisions regarding the analysis and interpretation of results. Compared to more direct methods for determining geographic movements, the main drawback of stable isotope models is a lack of spatial precision. Nevertheless, if research questions are cast to account for comparatively coarse spatial scales, the benefits are that information can be obtained for animals with no capture history and, therefore, is especially useful for species that are rare and sparsely distributed or for individuals that are first found dead. Study of the effects of renewable energy to wildlife stands to benefit appreciably from increased application of stable isotope data to assess origin, migratory status, and geographic structure of managed populations.

CHAPTER 5: Geographic Origin of Avian Fatalities at Renewable Energy Facilities in California

Introduction

A growing body of literature has used stable isotope approaches to study the migration and connectivity patterns of terrestrial organisms (Hobson and Wassenaar 2008; Hobson et al. 2010). Despite the power of the approach to retrospectively determine the geographic origin of dead wildlife, there have been few applications of stable isotopes to assess the origin of wildlife fatalities associated with renewable energy (Pylant et al. 2016; Katzner et al. 2017). In one study, geospatial analyses of δ^2H values obtained from golden eagle feathers killed at a wind facility in California were used to demonstrate that immigration to the local population was maintaining the stable demographic trends of the species (Katzner et al. 2017).

The purpose of this part of the study was to conduct the first large-scale assessment of geographic catchment areas for avian species commonly killed at wind and solar facilities. By using feathers obtained from regular monitoring efforts and from carcass searches at several wind and solar facilities across California, the authors assessed the geographic scope of commonly killed species as well as those of conservation concern. They report the portion of the population that was consistent with having originated locally versus the portion that may have originated from outside the collection region. Ultimately, effective management and mitigation efforts will require information about the demographic scope of the population from which fatalities are drawn.

Methods

Sample Collection

The authors, through collaboration with colleagues, obtained feather samples from avian carcasses from one wind facility and six solar facilities in California (Table 3, Figure 14). Carcasses were stored frozen until they were sampled on site or shipped to the USGS Snake River Field Station in Boise, Idaho, where they were thawed before feathers were collected. This study aimed to collect samples from 32 priority species identified based on their conservation relevance, numbers killed at renewable energy facilities, and the degree to which information on these species was available, via a panel of stakeholders, managers, and collaborators (Appendix A), although samples were only available for 25 of these species (Table 4). The feather type analyzed was based on the species body size. Flight feathers (wing or tail, which could not always be distinguished in feather piles that remained after carcasses had been scavenged following their death) were sampled from smaller species, such as songbirds. Body feathers were sampled from larger species, such as raptors, because flight feathers in large species typically grow more slowly and would potentially incorporate more isotopic variation (Wassenaar 2008). Search teams collected samples from the wind facility between March 2007 and September 2017 and from solar facilities between September 2013 and May 2017.

Table 3: Number of Individuals Sampled at Renewable Energy Facilities

Facility Type	Facility Name	Number of Individuals Sampled
Wind	Altamont Pass Wind Resource Area	411
Solar	Blythe Solar Energy Center	4
	Desert Sunlight Solar Farm	40
	Genesis Solar Energy Center	130
	Ivanpah Solar Electric Generating System	297
	McCoy Solar Energy Center	2
	Mojave Solar Project	42

Total number of individuals sampled at wind and solar facilities in California, from which feathers were obtained for analysis.

Source: U.S. Geological Survey

Table 4: Priority Species for Study

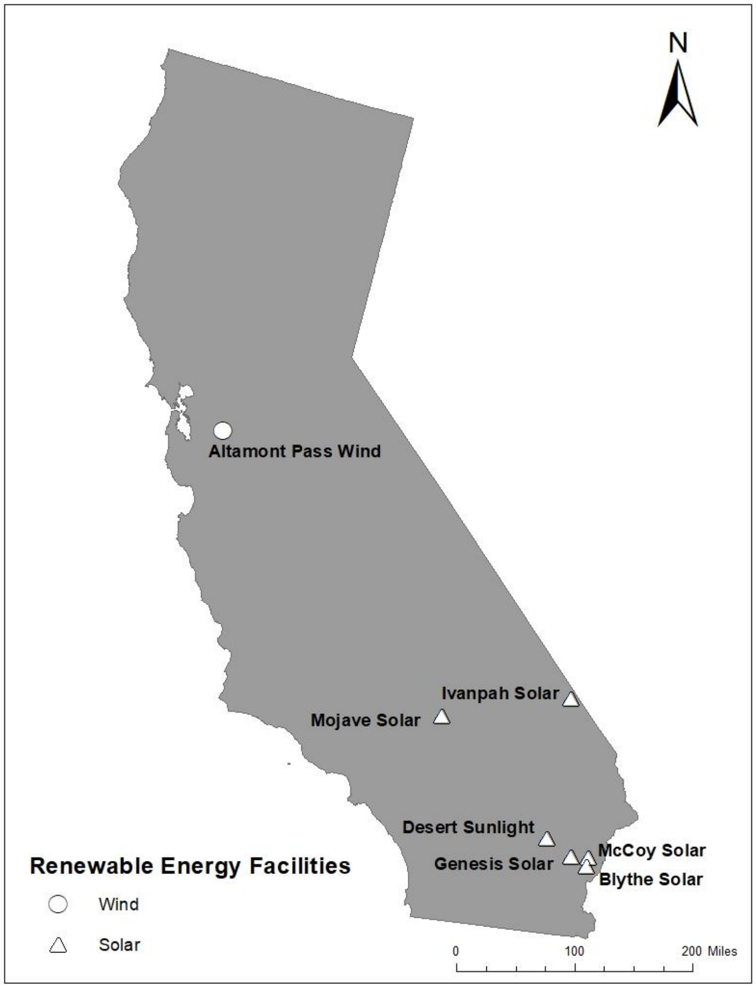
Species	Code	Scientific Name	Wind	Solar	Feather Type	Molt Timing
American kestrel	AMKE	*Falco sparverius*	Y	Y	Body	Breeding
American white pelican	AWPE	*Pelecanus erythrorhynchos*				Breeding
Bank swallow	BANS	*Riparia*				Begin summer, end winter
Barn owl	BANO	*Tyto alba*	Y		Flight	Summer
Black rail	BLRA	*Laterallus jamaicensis*				Breeding
Burrowing owl	BUOW	*Athene cunicularia*	Y		Body	Start summer, end winter
Common loon	COLO	*Gavia immer*		Y	Body	Breeding and winter
Common yellowthroat	COYE	*Geothlypis trichas*		Y	Flight	Summer
Eared grebe	EAGR	*Podiceps nigricollis*		Y	Body	Begin breeding, mostly stopover
Golden eagle	GOEA	*Aquila chrysaetos*	Y		Body	Breeding
Great horned owl	GHOW	*Bubo virginianus*	Y		Body	Summer
Greater roadrunner	GRRO	*Geococcyx californianus*		Y	Body	Irregular
Horned lark	HOLA	*Eremophila alpestris*	Y	Y	Flight	Summer
House finch	HOFI	*Haemorhous mexicanus*	Y	Y	Flight	Summer
Lesser nighthawk	LENI	*Chordeiles acutipennis*		Y	Flight	Summer
Mourning dove	MODO	*Zenaida macroura*	Y	Y	Flight	Summer
Red-necked phalarope	RNPH	*Phalaropus lobatus*		Y	Flight	Stopover and nonbreeding
Red-tailed hawk	RTHA	*Buteo jamaicensis*	Y		Body	Breeding
Ruddy duck	RUDU	*Oxyura jamaicensis*		Y	Body	Breeding and nonbreeding
Rufous hummingbird	RUHU	*Selasphorus rufus*		Y	Flight	Winter
Swainson's hawk	SWHA	*Buteo swainsoni*				Year-round
Tree swallow	TRES	*Tachycineta bicolor*		Y	Flight	Summer
Tricolored blackbird	TRBL	*Agelaius tricolor*				Summer

Species	Code	Scientific Name	Wind	Solar	Feather Type	Molt Timing
Western grebe	WEGR	*Aechmophorus occidentalis*		Y	Body	Stopover or nonbreeding
Western meadowlark	WEME	*Sturnella neglecta*	Y	Y	Flight	Summer
Western yellow-billed cuckoo	YBCU	*Coccyzus americanus occidentalis*				Winter
White-crowned sparrow	WCSP	*Zonotrichia leucophrys*		Y	Flight	Summer and winter
White-tailed kite	WTKI	*Elanus leucurus*	Y		Body	Breeding
Willow flycatcher	WIFL	*Empidonax traillii*				Winter
Wilson's warbler	WIWA	*Cardellina pusilla*	Y	Y	Flight	Summer
Yellow warbler	YEWA	*Setophaga petechia*		Y	Flight	Summer
Yellow-rumped warbler	YRWA	*Setophaga coronata*		Y	Flight	Summer and winter

List of 32 priority species for study and an indication of whether samples were obtained from individuals at each facility type, feather type that was analyzed, and information about the molt timing.

Source: U.S. Geological Survey; Pyle 1997, 2008 for the molt timing

Figure 14: Map of Sampling Sites



Locations of wind and solar renewable energy facilities where samples were collected.

Source: U.S. Geological Survey

Sample Analysis

All samples were sent to the Central Appalachians Stable Isotope Facility (CASIF) at the University of Maryland Center for Environmental Science's Appalachian Laboratory (Frostburg, Maryland) for preparation and analysis. Details of the analysis method are provided elsewhere (Nelson et al. 2015; Katzner et al. 2017; Vander Zanden et al. 2018) and in Appendix B.

Geographic Assignment Process

Before beginning the assignment process for waterbird species, the authors first checked for the possibility of marine influence in diet (Vander Zanden et al. 2018). Subsequently, following the assignment process steps in Chapter 4 and Vander Zanden et al. (2018), the authors first selected one of two baseline precipitation isoscapes: growing season (Bowen, Wassenaar, and Hobson 2005) or mean annual (Bowen and

Revenaugh 2003), obtained from waterisotopes.org. Next, they rescaled the precipitation δ^2H values to feather δ^2H values for each species using previously published linear regressions that were selected to match the species and precipitation isoscapes as closely as possible. Finally, they trimmed the isoscapes to the species range obtained from BirdLife International and *Handbook of the Birds of the World* (2016), although in a few cases, the entire North American continent was used when the collection site was part of the migration range.

The authors included three levels of variance in the calculation of conditional probabilities: the variance in the precipitation isoscapes, the variance among individuals, and the analytical variance. They calculated a standard deviation corresponding to the precipitation isoscape from the 95 percent confidence interval grid by dividing the confidence interval value for each pixel by 1.96. Confidence interval grids were not available for the growing season isoscapes when the work began, and thus, the authors used the mean annual standard deviation map for all assignments. They calculated individual variance from the dataset itself. They analyzed three separate feathers for multiple individuals of each species and used the mean standard deviation from 1 to 73 individuals (Table 5, Table 6). Finally, they calculated the analytical standard deviation as the long-term variability in replicates of the internal keratin standard at the CASIF lab, which was 2.3 per mil. Assuming each of these measures of variance were independent, the authors calculated a pooled variance, yielding a variance for each pixel of the considered range.

Table 5: Summary of Wind Geographic Assignments for 12 Species

Species Code	Range	Feathers	N	Marine	Iso-scape	Species SD	SD Indv	Slope	Inter-cept	Assigned	Local	Non-local	Prop Local	Prop Non-local	Group
AMKE	Species	55	42	NA	GS	12.2	1	1.3	26.59	42	32	10	0.76	0.24	R
BANO	Species	65	54	NA	GS	4.9	6	1.3	26.59	54	10	44	0.19	0.81	R
BUOW	Species	48	37	NA	GS	3.6	6	1.3	26.59	37	12	25	0.32	0.68	R
GHOW	Species	62	43	NA	GS	4.6	12	1.3	26.59	43	27	16	0.63	0.37	R
GOEA	Species	285	76	1	GS	7.4	73	0.95	2.69	75	49	26	0.65	0.35	R
HOFI	Species	1	1	NA	GS	8.6	6	0.95	-11.2	1	0	1	0	1	P
HOLA	Species	56	43	NA	GS	12.4	5	0.95	-11.2	43	33	10	0.77	0.23	P
MODO	Species	6	6	NA	GS	7.2	10	0.97	-30.2	6	6	0	1	0	P
RTHA	Species	131	86	NA	GS	5.6	9	1.3	26.59	86	33	53	0.38	0.62	R
WEME	Species	25	15	NA	GS	4.9	8	0.95	-37	15	3	12	0.2	0.8	P
WIWA	Species	5	5	NA	GS	3.1	5	0.95	-17.6	5	3	2	0.6	0.4	P
WTKI	Species	6	3	NA	GS	7.6	2	1.3	26.59	3	3	0	1	0	R
Raptor		652	341	1						340	166	174	0.49	0.51	
Pass-erine		93	70	NA						70	45	25	0.64	0.36	
Total		745	411	1						410	211	199	0.51	0.49	

Species Code refers to the species sampled (see Table 4 for the species name associated with the code); Range indicates the species range obtained from BirdLife International; Feathers refers to the number of total feathers obtained for δ^2H analysis; N is the number of individuals from which feathers were obtained; Marine indicates the number of individuals with potential marine influence that were removed from further analysis; Isoscape was always growing season (GS); Species SD indicates the mean standard deviation among individuals calculated from birds from which at least three feathers were obtained; SD Indv indicates the number of individuals used for the previous calculation, Slope and Intercept refer to the parameters in the rescaling function; Assigned is the number of individuals assigned after removing the marine samples; Local and Nonlocal refer to the number of individuals with that designation; Prop Local and Prop Nonlocal are the relative proportions of individuals with each designation, and Group refers to the species clade for subtotals reported at the bottom of the table (P = passerine, R = raptor).

Source: U.S. Geological Survey; Bowen, Wassenaar, and Hobson (2005); Wunder et al. (2009); Hobson et al. (2012b); Carleton, Rio, and Robinson (2015); BirdLife International and Handbook of the Birds of the World (2016); Vander Zanden et al. (2018)

Table 6: Summary of Solar Geographic Assignments for 19 Species

Species Code	Range	Feathers	N	Marine	Iso-scape	Species SD	SD Indv	Slope	Inter-cept	Assigned	Local	Non-local	Prop Local	Prop Non-local	Group
AMKE	Species	79	19	NA	GS	12.2	8	1.3	26.59	19	5	14	0.26	0.74	R
COLO	Species	16	7	6	GS	11.3	6	0.93	-31.6	0[a]	0	0	0	0	W
COYE	Species	29	17	NA	GS	2	6	0.55	-47.6	17	6	11	0.35	0.65	P
EAGR	Species	128	54	15	GS	10.1	14	0.93	-31.6	39	9	30	0.23	0.77	W
GRRO	Species	56	26	NA	GS	5.9	8	1.3	26.59	26	18	8	0.69	0.31	O
HOLA	Species	34	26	NA	GS	12.4	5	0.95	-11.2	26	17	9	0.65	0.35	P
HOFI	Species	26	16	NA	GS	8.6	6	0.95	-11.2	16	3	13	0.19	0.81	P
LENI	Species	33	23	NA	GS	4.3	7	0.95	-23	23	4	19	0.17	0.83	O
MODO	Species	81	41	NA	GS	7.2	10	0.97	-30.2	41	16	25	0.39	0.61	P
RNPH	NAmer	9	3	0	GS	6	3	0.93	-31.6	3	0	3	0	1	W
RUDU	NAmer	82	23	2	GS	8.5	11	0.93	-31.6	21	0	21	0	1	W
RUHU	NAmer	25	15	NA	MA	8.1	5	0.87	-25	15	1	14	0.07	0.93	O
TRES	Species	37	27	NA	GS	5.4	6	0.95	-23	27	8	19	0.3	0.7	P
WEGR	Species	49	22	2	GS	8.8	5	0.93	-31.6	20	15	5	0.75	0.25	W
WEME	Species	109	35	1	GS	8	8	0.95	-37	34	21	13	0.62	0.38	P
WCSP	Species	61	51	NA	GS	10.7	6	0.95	-37	51	4	47	0.08	0.92	P
WIWA	Species	26	17	NA	GS	3.1	5	0.95	-17.6	17	3	14	0.18	0.82	P
YEWA	Species	44	34	NA	GS	3	6	0.95	-17.6	34	0	34	0	1	P
YRWA	Species	69	59	NA	GS	4	6	0.95	-17.6	59	1	58	0.02	0.98	P
Raptor		79	19	NA						19	5	14	0.26	0.74	
Pass-erine		516	323	1						322	79	243	0.25	0.75	
Water-bird		284	109	25						83	24	59	0.29	0.71	
Other		114	64	NA						64	23	41	0.36	0.64	
Total		993	515	26						488	131	357	0.27	0.73	

Species Code refers to the species sampled (see Table 4 for the species name associated with the code); Range indicates whether the species range obtained from BirdLife International or the entire North American continent (NAmer) was used; Feathers refers to the number of total feathers obtained for δ^2H analysis; N is the number of individuals from which feathers were obtained; Marine indicates the number of individuals with potential marine influence that were removed from further analysis; Isoscape used was growing season (GS), except for RUHU for which the mean annual (MA) isoscape was used; Species SD indicates the mean standard deviation among individuals calculated from birds from which at least three feathers were obtained; SD Indv indicates the number of individuals used for the previous calculation, Slope and Intercept refer to the parameters in the rescaling function; Assigned is the number of individuals

assigned after removing the marine samples; Local and Nonlocal refer to the number of individuals with that designation; Prop Local and Prop Nonlocal are the relative proportions of individuals with each designation, and Group refers to the species clade for subtotals reported at the bottom of the table (O = Other, P = passerine, R = raptor, W = waterbird). [a]The one COLO that was not designated as marine had $\delta^{15}N$ values (but not $\delta^{13}C$ values) above the marine cutoff and also had very high variance in $\delta^{2}H$ values, so it was not considered further.

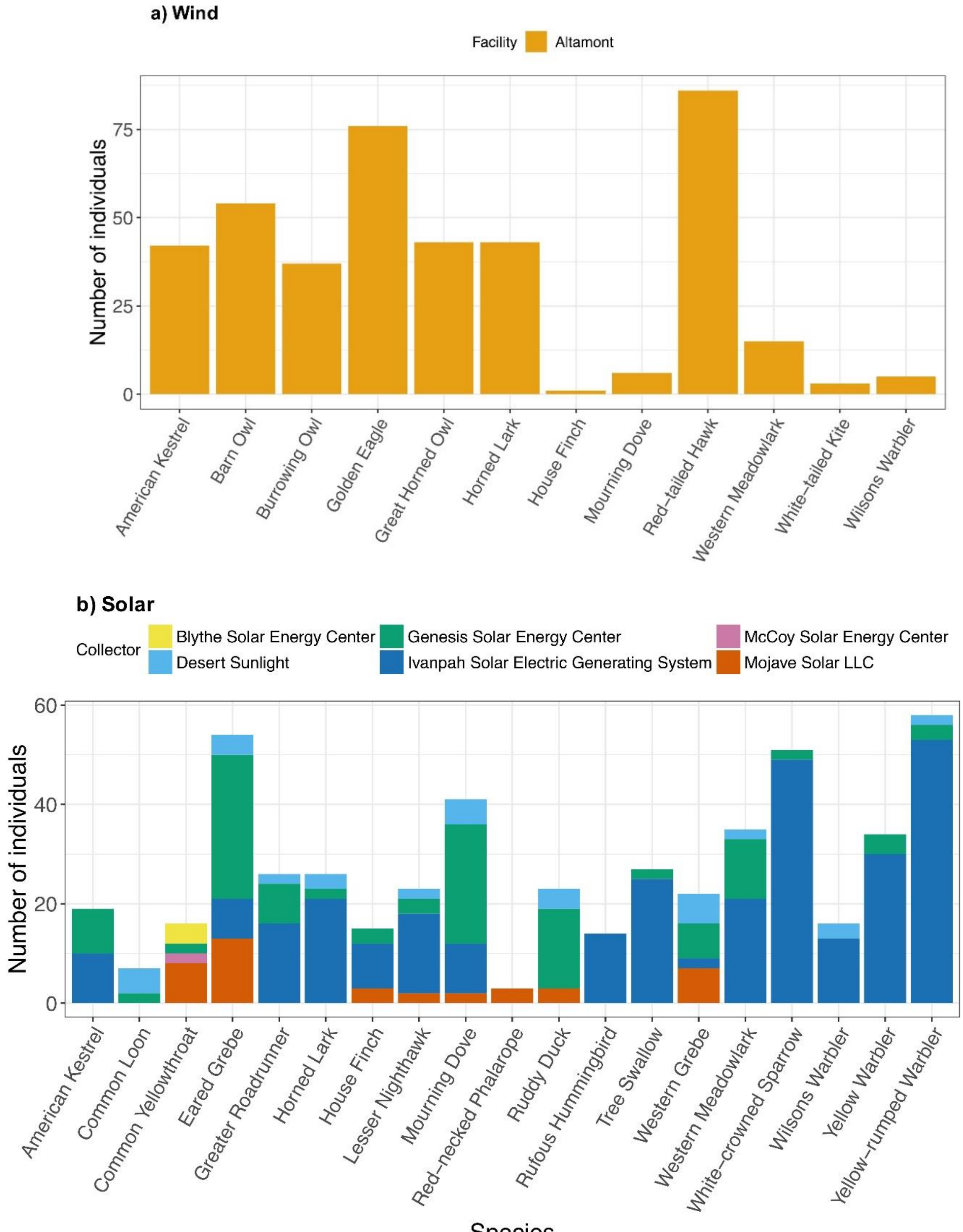
Source: U.S. Geological Survey; Bowen and Revenaugh (2003); Bowen, Wassenaar, and Hobson (2005); Clark, Hobson, and Wassenaar (2009); Wunder et al. (2009); Hobson et al. (2012b); Moran et al. (2013); Carleton, Rio, and Robinson (2015); BirdLife International and Handbook of the Birds of the World (2016)

The authors calculated the posterior probabilities for each feather originating from each pixel as a normal density function following the procedure outlined in Chapter 4 and Vander Zanden et al. (2018), with a resulting raster in which all cells sum to 1. To define a local versus nonlocal status for each individual, the authors considered the odds ratio of the pixel of capture. The authors used a 5:1 odds ratio based on previous evaluations across a range of thresholds that showed accuracy began to level out at this threshold (Vander Zanden et al. 2018). Thus, the pixel value of capture had to be greater than or equal to an OR value of 0.167 to be considered local. Note that a local designation meant that the feather isotope value was consistent with having been grown in that pixel, but also many other pixels met the same threshold as well. From this local or nonlocal designation, the authors calculated the proportion of individuals classified into each category. To create summary maps for each species, the authors summed the maps for all individuals in each of the local or nonlocal categories and divided by the total to calculate a mean surface. The authors used the software R (R Core Team 2016) for all analyses conducted in this chapter.

Results

The authors analyzed a total of 745 feathers from 411 individuals of 12 species collected at APWRA (Figure 15). They analyzed a total of 993 feathers from 515 individuals of 19 species collected at solar facilities, with samples from each of three types of facilities (photovoltaic, parabolic troughs, and power towers), although the majority came from Ivanpah Solar Electric Generating System (power tower) and Genesis Solar Energy Center (trough**;** Figure 15).

Figure 15: Priority Species from Which Feathers were Collected at Renewable Energy Facilities

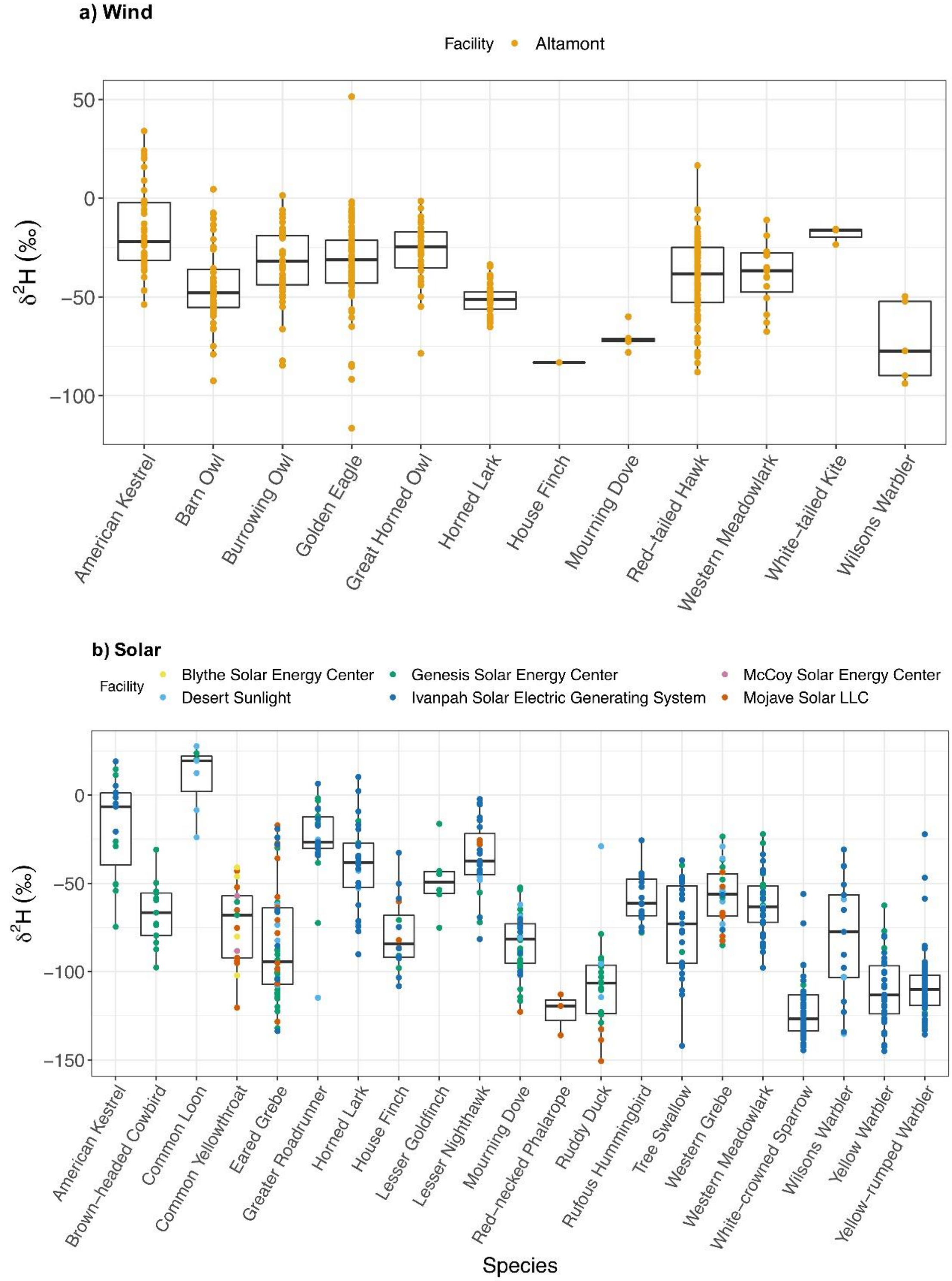


Number of individuals of each priority species from which feathers were collected at a) one wind and b) six solar facilities. Total number of individuals was 411 (wind) and 515 (solar).

Source: U.S. Geological Survey

The δ^2H values varied both within and among species (Figure 16). The use of $\delta^{13}C$ and $\delta^{15}N$ values identified 26 individuals with potential marine influence, including 6 common loons (*Gavia immer*), 15 eared grebes (*Podiceps nigricollis*), 2 ruddy ducks (*Oxyura jamaicensis*), 2 western grebes (*Aechmophorus occidentalis*), and 1 western meadowlark (*Sturnella neglecta*) from solar facilities (Figure 17). One golden eagle from the wind facility also had potential marine influence based on its high δ^2H value (>25 per mil), even though it did not quite meet the cutoff for $\delta^{13}C$ and $\delta^{15}N$ values (-21.49 and 11.1 per mil, respectively). These individuals were removed from further analysis. Eliminating six of seven common loons left only one for assignment. This loon had $\delta^{15}N$ values (but not $\delta^{13}C$ values) above the marine cutoff and also had very high variance in δ^2H values, so it was not considered further. Marine input was not expected in the western meadowlark, but it is possible that the high $\delta^{13}C$ and $\delta^{15}N$ values in the single individual could indicate use of an agricultural area. Therefore, the total number of assignments made based on δ^2H values were 410 individuals from the wind facility (Table 5) and 488 individuals from solar facilities (Table 6).

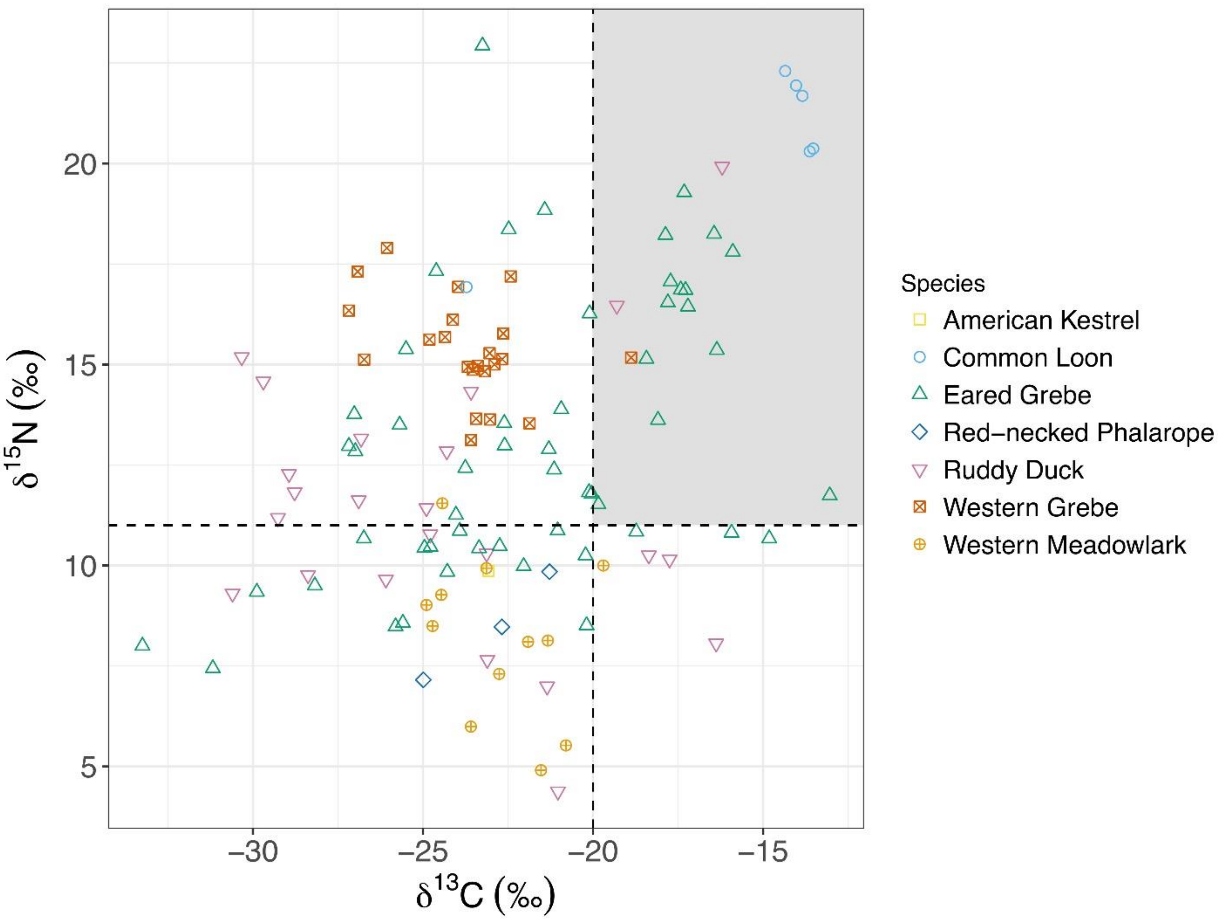
Figure 16: Feather Hydrogen Isotope Values Collected From Priority Species



Range of feather hydrogen isotope (δ^2H) values collected from priority species with three or more individuals at a) wind and b) solar facilities. Each point represents an individual, with mean δ^2H values if more than one feather sample was analyzed.

Source: U.S. Geological Survey

Figure 17: Biplot of $\delta^{13}C$ and $\delta^{15}N$ Values for Solar Fatalities

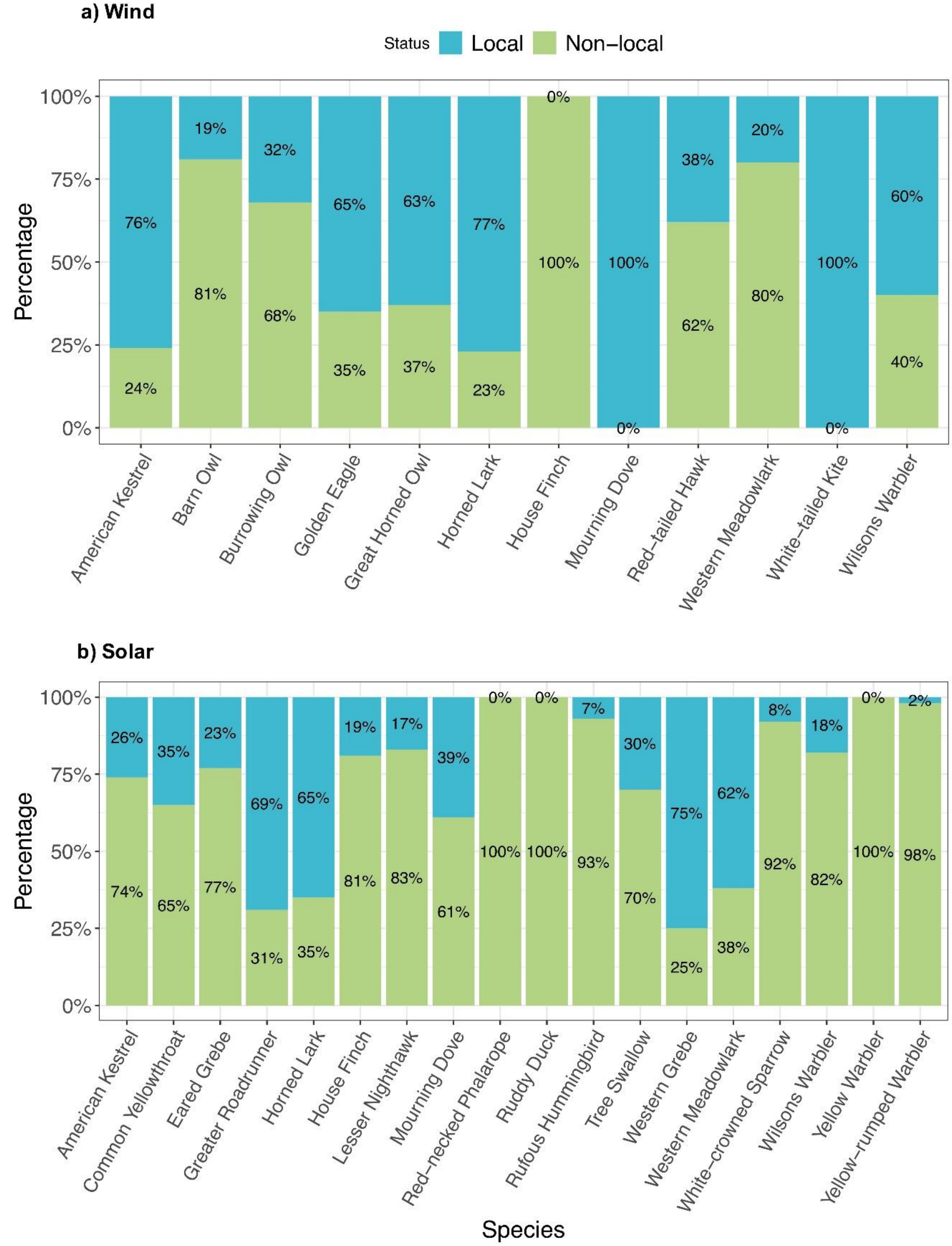


Plot of mean $\delta^{13}C$ and $\delta^{15}N$ values of individuals from solar facilities for which the potential for marine influence was investigated. The gray area ($\delta^{13}C$ >-20 per mil and $\delta^{15}N$ >11 per mil) includes individuals that were considered to have marine influence, and thus were not considered in further analyses. These include 6 common loons, 15 eared grebes, 2 ruddy ducks, 2 western grebes, and 1 western meadowlark. The mean values for one western grebe and the western meadowlark were outside the gray shaded area but had individual feathers within this range, so these individuals were also considered to have marine influence.

Source: U.S. Geological Survey

The percentage of birds that grew feathers at a location outside the collection site ranged from 24 percent to 100 percent (mean ± SD = 49 percent ± 33 percent) at wind facilities and 25 percent to 100 percent (73 percent ± 25 percent) at solar facilities (Figure 18). The distribution of fatalities across the months of the year was fairly consistent at wind facilities, with spring and fall peaks in the number of fatalities at solar facilities in the months of April, September, and October (Figure 19). These are migratory periods that also corresponded to high nonlocal percentages of 77 percent to 82 percent of the fatalities in those months.

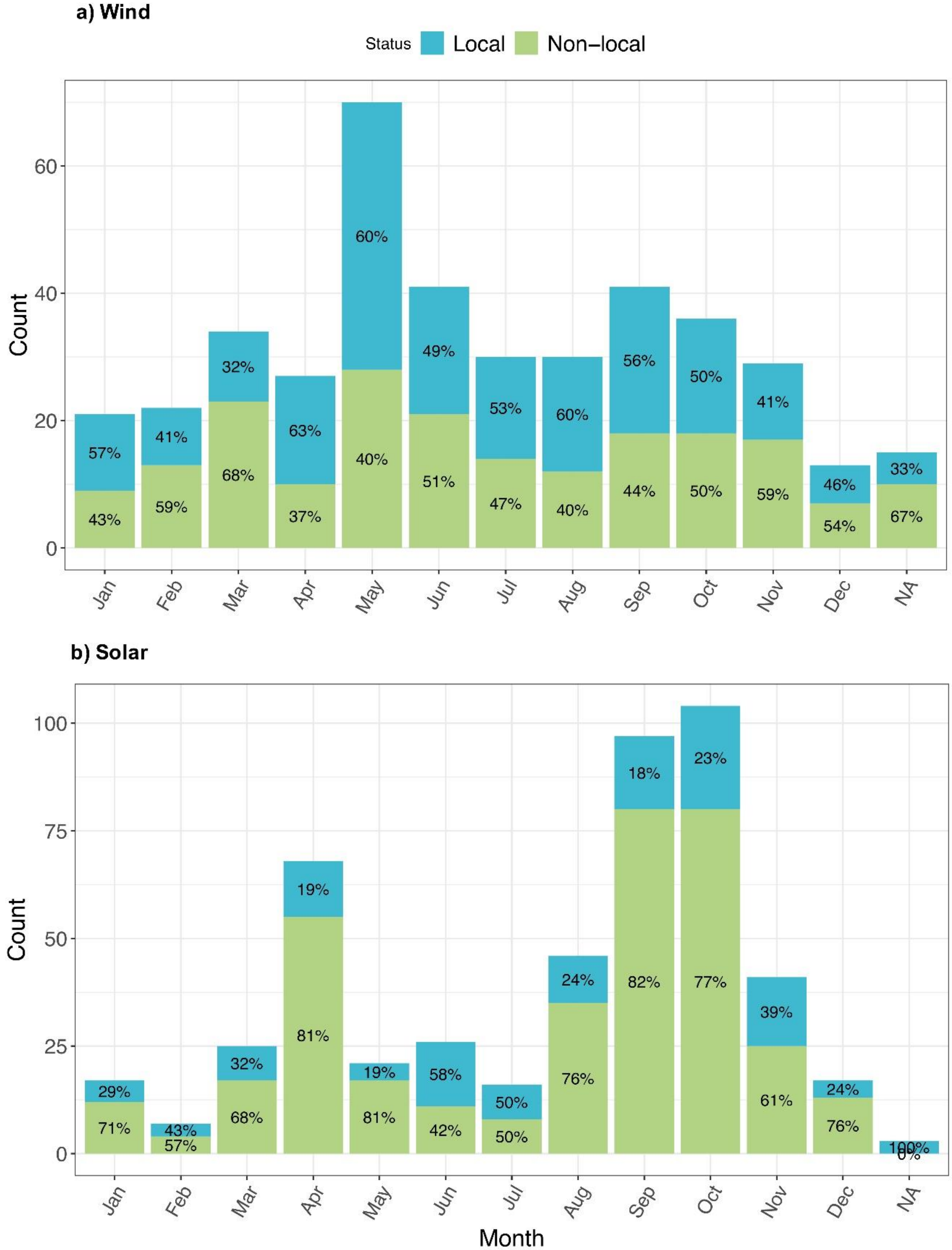
Figure 18: Percentages of Local vs. Nonlocal Geographic Origin



Proportion of individuals for which the geographic origin was local or nonlocal based on feather δ^2H values at a) wind and b) solar facilities.

Source: U.S. Geological Survey

Figure 19: Fatalities by Month



Distribution of fatalities across the months of the year (all years combined) with percent local vs. nonlocal indicated on each bar for a) wind and b) solar facilities. The NA bar indicates samples for which the collection month was not available.

Source: U.S. Geological Survey

Discussion

The geographic origin of birds killed at renewable energy facilities comprises a large portion of individuals that likely originated from outside the immediate region of the location of death. The proportion of fatalities that had a nonlocal origin was higher at solar facilities based in Southern California (73 percent) compared to wind facilities (49 percent). Therefore, the geographic catchment area of impact extends much farther than the local region of wind and solar energy generation. These results are an important step in identifying potential immigration rates to build demographic models that can interpret whether the fatalities induced by renewable energy facilities are demographically sustainable for the species affected.

The pattern in the fatalities of birds at solar facilities was more seasonal with peaks that correspond with migration periods in the spring (April) and fall (September and October), when 77 percent or more of the birds were determined to be nonlocal. In contrast, the seasonality of the fatalities at the wind facilities was more dampened. This may have implications for mitigation efforts to target time-specific periods, particularly at Southern California solar facilities, when migratory birds may be most at risk for fatalities.

In addition, there was limited overlap in the species found among wind and solar facilities: only 6 of the 25 species sampled in this study were found in sufficient numbers at both facility types. While the sampling does not necessarily represent standardized effort among facility types and does not incorporate samples from all species killed or measures of detection rates for differently sized and colored species, such differences among the types of species killed has been documented previously. Passerines comprise the majority of birds killed at solar facilities in Southern California (Walston et al. 2016). While passerines comprised 62.5 percent of the observed fatalities at wind energy facilities across the United States (Erickson et al. 2014), the APWRA has a notably higher rate of raptor fatalities, comprising an estimated 42 percent of the fatalities at that site (Smallwood and Thelander 2008; Smallwood 2013).

These species abundance differences are likely driven by the differences in the surrounding habitat. APWRA consists of hilly terrain with grasslands where California ground squirrels (*Otospermophilus beecheyi*) are common and raptors forage most when combinations of topography and weather produce wind currents that are ideal for soaring and kiting. The latter flight type puts raptors at high risk because it occurs primarily in strong winds and puts them at the height of the rotating wind blades (Hoover 2002).

In contrast, Southern California sits within the Pacific Flyway used by migrating passerines and waterbirds. One of the most important stops along this flyway is the Salton Sea, which is a critical habitat for wintering, migratory, and breeding waterbirds (Shuford et al. 2002). Waterbirds made up 21 percent of the solar fatalities in the study. It has been suggested that water-dependent species are vulnerable to fatalities at solar facilities because of the so-called lake effect in which solar arrays are confused with bodies of water, a phenomenon that may be dependent on the size and continuity of panels (Kagan et al. 2014) and also the species (Fernandez-Juricic, Baumhardt, and Kelly 2018). For example, many of the western grebes that were classified as local also had feather δ^2H values consistent with other parts of the nearby region, which included the Salton Sea. This species has pre-alternate molts of some to all body feathers mostly or entirely on nonbreeding grounds (Pyle 2008), suggesting that the sampled feathers could represent their use of nearby wintering habitat.

The isotopic predictions for local and nonlocal assignments were generally compatible with the known biology of the species. For example, California lies between breeding and wintering range of the rufous hummingbird (*Selasphorus rufus*), red-necked phalarope (*Phalaropus lobatus*), and yellow warbler (*Setophaga petechia*), so all of the fatalities of these species were expected to be nonlocal. The molting period of the rufous hummingbird occurs during the winter (Pyle 1997), and 14 of the 15 geographic assignments were consistent with locations in the winter range within Mexico, while the single local individual had high probability both at the site of capture and slightly south into Mexico. The red-necked phalarope has prebasic molts of most body feathers that commence at stopover sites and complete on nonbreeding grounds (Pyle 2008). While there were only three individuals of this species, areas of high probability of origin occurred in the migratory range. Finally, primary basic molt of yellow warblers occurs on the summer grounds (Pyle 1997), and all individuals had origins consistent with more northern latitudes, mostly in the breeding range.

The majority of golden eagle fatalities (67 of 75 individuals) had been previously analyzed by Katzner et al. (2017), in which stable isotope analysis suggested that 26 percent of individuals were nonlocal. The nonlocal percentage calculated here was slightly higher (35 percent) but may be attributed to slightly different methods between the two studies, including the use of different precipitation isoscapes, different rescaling functions, and a spatial buffer around the known sampling origin (Katzner et al. 2017). The previous results were also consistent with demographic models that predicted 28 percent of the population in any given year was comprised of individuals that immigrated (Katzner et al. 2017).

The results for house finches were surprising, in that most feather samples from solar facilities (13 of 16 individuals) and the single feather sample from the wind facility were considered to have grown outside the collection site. This species is considered resident in California and is not known to migrate long distances. However, some short-distance movements between mountain slopes in the summer and desert valleys in the winter have been reported (Badyaev, Belloni, and Hill 2012). Because of the large isotopic differences between high altitudes and low altitudes, these short-distance movements may be long enough to result in a nonlocal classification.

The greater roadrunner (*Geococcyx californianus*) results were also unanticipated. The mode of death is not due to collision with panels, as the greater roadrunners were often found near the fence line of these facilities, and it is possible that predators are using the fence to facilitate capture of roadrunners as prey (P. Sazenbacher, pers. comm.). This is substantiated by the fact that nearly all of the samples obtained originated from feather spots rather than intact carcasses. Next, 31 percent (8 of 26) of the greater roadrunners were designated nonlocal, which was surprising for a species that is not reported to migrate (Hughes 2011). The probable locations of many of the nonlocal individuals were very close to the collection site, which does not indicate they were undertaking medium- to long-range migratory movements. Nevertheless, the nonlocal designations might be explained in one of two ways. First, this species uses chaparral habitat up to 4,000 meters in elevation (Unitt 2004), and altitudinal migration can result in isotopic differences similar to those observed in latitudinal migrating individuals. Second, the authors elected to use the raptor precipitation-feather rescaling function, assuming the diet of the greater roadrunner would be similar to a raptor, as there were no other published regressions for this species or a species closely matched to the ecological characteristics of the greater roadrunner. Thus, it is possible that using a rescaling function derived from greater roadrunner data could change the results.

In conclusion, this initial analysis suggests that a large portion of birds killed at renewable energy facilities originates from areas beyond the immediate site of the facility, and this differs with the facility type and species. Planned future analyses consist of further subdividing the solar facilities by type (photovoltaic, trough, and power tower) to report summary statistics; evaluating the local vs. nonlocal determination over a range of odds ratios thresholds; refinement of analyses for those species for which results were inconclusive; and calculating a distance metric that characterizes the distance from the capture point to the maximum point of the posterior probability surface.

CHAPTER 6: Demography of Wildlife Species Affected by Renewable Energy Facilities in California

Introduction

In spite of the broad estimates available about the number of individuals killed at renewable energy facilities, the effect these mortality rates may have on the stability of regional or continental-scale populations of a given species remains largely unknown. Understanding how and why population size changes over time and identifying the demographic rates that drive shifts in population size is a common focus of wildlife ecology research. However, identifying and quantifying vital rates within the context of spatial and temporal variation is a continuing challenge for most species (Nichols 1996; Marra et al. 2015; Rushing et al. 2017). Integrated population models (IPMs) are a recent development of a modeling framework designed to incorporate structured population models (Caswell 2001) along with data from multiple sources to concurrently estimate population growth and vital rates including survival, fecundity, or immigration (Besbeas et al. 2002; Brooks, King, and Morgan 2004; Schaub and Abadi 2011; Marra et al. 2015).

Given the rapid growth of renewable energy, it is urgent to understand the population-level consequences of wildlife fatalities at renewable facilities. The objectives here were to estimate demographic parameters for multiple avian and bat species of conservation interest and to determine the impacts of potential renewable-driven decrease in survival on the stability of these wildlife populations. The authors then use this information to evaluate the potential effects of renewable energy development on these wildlife species.

Methods

The authors used the same list of 32 avian species described in Chapter 5, plus 2 bat species of interest to renewable energy development in California (Table 7; Appendix A). For each species, the authors conducted a literature search using online species accounts (Birds of North America 2015) and search engines to find peer-reviewed or unpublished reports containing estimates of demographic parameters, including juvenile survival (birth to 1 year old; Φ_{1y}), adult survival (Φ_{a}), and fecundity (number of offspring produced per breeding individual in a given year; *fec*). For species that require multiple years to reach breeding maturity, the authors also collected literature-based estimates of pre-adult survival (1 year old to breeding age; Φ_{2y}) when they were available. If no data were available for a given species, the authors searched for available estimates among congenerics or closely related species. The authors calculated weighted mean and unconditional variance for each parameter to use in subsequent analyses. If literature estimates were missing both standard deviation (*SD*) and standard error (*SE*), they used *SE* = 0.2 for survival and *SE* = 2 for fecundity.

Table 7: Prior Distributions for Survival and Fecundity Parameters for 34 Species

Species	Prior Distributions		
	Juvenile Survival (Φ_{1y})	**Adult Survival (Φ_a)**	**Fecundity (*fec*)**
American kestrel	*Beta*(0.59, 4.17)	*Beta*(4.14, 2.58)	*Gamma*(11.95, 11.02)
American white pelican	*Beta*(2.98, 2.07)	*Beta*(2.49, 0.66)	*Gamma*(0.1, 0.32)
Bank swallow	*Beta*(1, 2.44)	*Beta*(2.09, 2.96)	*Gamma*(2,535.57, 1,228.96)
Barn owl	*Beta*(1.92, 4.19)	*Beta*(0.74, 0.47)	*Gamma*(1.64, 1.13)
Black rail	–	–	–
Burrowing owl	*Beta*(21.03, 56.06)	*Beta*(2.74, 3.19)	*Gamma*(1.4, 1.08)
Common loon	*Beta*(2.07, 2.98)	*Beta*(0.77, 0.07)	*Gamma*(4.47, 15.67)
Common yellowthroat	*Beta*(2, 2)	*Beta*(1,964.27, 1,940.84)	*Gamma*(475.24, 872)
Eared grebe	*Beta*(1.57, 3.04)	*Beta*(2.77, 0.92)	*Gamma*(2.41, 1.54)
Golden eagle	*Beta*(41.56, 8.03)	*Beta*(29.43, 1.92)	*Gamma*(0.25, 0.5)
Great horned owl	*Beta*(8.63, 6.06)	*Beta*(14.33, 4.31)	*Gamma*(0.49, 0.68)
Greater roadrunner	*Beta*(2, 2)	*Beta*(1.8, 3.22)	*Gamma*(0.66, 0.75)
Hoary bat	–	–	–
Horned lark	*Beta*(5.01, 47.72)	*Beta*(25.5, 24.5)	*Gamma*(247.87, 272.39)
House finch	*Beta*(2, 2)	*Beta*(34.67, 36.71)	*Gamma*(13.27, 10.28)
Lesser nighthawk	*Beta*(2, 2)	*Beta*(2.07, 1.11)	*Gamma*(0.01, 0.01)
Mexican free-tailed bat	–	–	–
Mourning dove	*Beta*(46.85, 127.78)	*Beta*(52.84, 71.79)	*Gamma*(0.25, 0.5)
Red-necked phalarope	–	–	–
Red-tailed hawk	*Beta*(1.89, 2.75)	*Beta*(337.08, 97.86)	*Gamma*(0.49, 0.69)
Ruddy duck	–	–	–
Rufous hummingbird	*Beta*(2, 2)	*Beta*(24.9, 58.1)	*Gamma*(0.72, 0.85)
Swainson's hawk	*Beta*(38.16, 48.56)	*Beta*(163.67, 27.05)	*Gamma*(0.48, 0.69)
Tree swallow	*Beta*(2, 2)	*Beta*(2.37, 2.83)	*Gamma*(4.71, 2.12)
Tricolored blackbird	*Beta*(2, 2)	*Beta*(3, 2)	*Gamma*(0.1, 0.31)

Western grebe	*Beta*(2, 2)	*Beta*(2, 2)	*Gamma*(1,169.86, 2,658.74)
Western meadowlark	*Beta*(2, 2)	*Beta*(0.63, 0.51)	*Gamma*(14.7, 15.02)
Western yellow-billed cuckoo	*Beta*(2, 2)	*Beta*(122,968.02, 126,966.98)	*Gamma*(7.17, 9.57)
White-crowned sparrow	*Beta*(2, 2)	*Beta*(2.57, 2.68)	*Gamma*(2.64, 1.63)
White-tailed kite	*Beta*(1.4, 2.98)	*Beta*(2.84, 1.6)	*Gamma*(237.2, 261.95)
Willow flycatcher	*Beta*(2.63, 2.63)	*Beta*(1.13, 0.13)	*Gamma*(3.01, 2.31)
Wilson's warbler	*Beta*(2, 2)	*Beta*(525.28, 645.51)	*Gamma*(0.01, 0.01)
Yellow warbler	*Beta*(2, 2)	*Beta*(2,436.97, 1,854.81)	*Gamma*(1.12, 1.06)
Yellow-rumped warbler	*Beta*(0.66, 1.72)	*Beta*(201.54, 228.34)	*Gamma*(10.71, 37.57)

If no information for a given parameter for a species (or congeneric) was available, weakly informative priors of *Beta*(2,2) for survival and *Gamma*(0.01, 0.01) were used. Dashes (–) indicate no integrated population model was generated for that species.

Source: U.S. Geological Survey

The authors estimated population growth rates (hereafter λ) for avian species using strata-specific annual indices downloaded from the North American Breeding Bird Survey (BBS) website (https://www.mbr-pwrc.usgs.gov/bbs/BBS_Annual_Indices_Estimates_2015_7-29-2016.csv) for 1968–2015 (Sauer et al. 2017). BBS data are composed of counts conducted annually since 1966 (and in the western United States since 1968) to monitor more than 400 bird species in North America along more than 4,700 24.5-mile survey routes. The authors used California as the designated stratum except when data were unavailable, in which case they used the Western United States strata.

BBS creates stratum-specific annual indices of avian populations with a hierarchical model approach. Those models incorporated year, stratum, observer, and trend effects, and were scaled by the proportion of routes where a given species was detected and stratum area, to provide a mean number of individuals detected per survey route per stratum per year (Sauer and Link 2011). The authors used BBS-reported interannual change in the mean number of individuals per stratum (BBS calls these *BBS annual index estimates*) to estimate the λ used in subsequent analyses. Lambda is greater than 1 when the population is growing larger and less than 1 when a decline is predicted.

Modeling Framework

The authors developed a multi-age IPM to estimate species-specific survival and fecundity as a function of the BBS annual index estimates. The authors then built a matrix model to estimate demographic parameters that would result in the change in BBS population size observed from time t to $t + 1$. Finally, to implement the model, the authors used Markov chain Monte Carlo model implementation methods within a Bayesian framework using JAGS 3.4.0 (Plummer 2013) with the R package *jagsUI* (Kellner 2018). Details on these methods are provided in **Appendix C**.

Stable Isotopes to Determine Geographic Origin of Individuals Killed at Renewable Energy Facilities

The authors used the wildlife forensics approach detailed in Chapters 4 and 5 to estimate the potential area of origin of birds killed at renewable energy facilities. They determined the likely region of geographic origin by comparing δ^2H isotope composition in feathers collected from carcasses with species range-wide precipitation isoscapes to assess the location where feathers were grown and the likely region of geographic origin for that individual (classified as *local* or *nonlocal*). The authors then computed the proportion of individuals for each species classified in each origin category (Table 5, Table 6) and used these values to assess the relative size of the geographic catchment area, where a species with samples solely classified as local individuals would have a smaller catchment area than a species with a high proportion of nonlocals. The authors collected isotope data for analyses from 25 species (Table 4, Table 8).

Table 8: Summary of Juvenile and Adult Survival Demographic Parameters for 34 Species

Species	Species Guild	δ²H Data	Prior Constraints Φ	Prior Constraints *fec*	Juvenile Survival (Φ_{1y}) Estimate	Juvenile Survival SD	Juvenile 95% CrI Lower	Juvenile 95% CrI Upper	Adult Survival (Φ_a) Estimate	Adult Survival SD	Adult 95% CrI Lower	Adult 95% CrI Upper
American kestrel	Raptor	Wind, Solar	0.2	0.5	0.204	0.06	0.11	0.31	0.797	0.02	0.74	0.82
American white pelican	Waterbird	–	0.2	0.5	0.741	0.04	0.64	0.79	0.909	0.02	0.86	0.94
Bank swallow	Passerine	–	0.2	0.5	0.405	0.01	0.39	0.41	0.450	0.03	0.40	0.52
Barn owl	Raptor	Wind	0.2	0.5	0.261	0.09	0.13	0.45	0.908	0.03	0.84	0.96
Black rail	Waterbird	–	–	–	–	–	–	–	–	–	–	–
Burrowing owl	Raptor	Wind	0.1	0.3	0.363	0.02	0.32	0.40	0.546	0.02	0.50	0.58
Common loon	Waterbird	Solar	0.0	0.0	0.806	0.06	0.66	0.91	0.932	0.01	0.90	0.95
Common yellowthroat	Passerine	Solar	0.2	0.5	0.436	0.05	0.31	0.51	0.724	0.05	0.62	0.82
Eared grebe	Waterbird	Solar	0.2	0.5	0.147	0.02	0.11	0.19	0.871	0.03	0.81	0.91
Golden eagle	Raptor	Wind	0.1	0.25	0.849	0.04	0.77	0.91	0.946	0.01	0.93	0.96
Great horned owl	Raptor	Wind	0.2	0.3	0.452	0.04	0.32	0.58	0.922	0.02	0.84	0.95
Greater roadrunner	Other	Solar	0.2	0.5	0.339	0.04	0.23	0.41	0.611	0.06	0.53	0.77
Hoary bat	Bat	–	–	–	–	–	–	–	–	–	–	–
Horned lark	Passerine	Wind, Solar	0.0	0.0	0.231	0.05	0.15	0.32	0.731	0.04	0.64	0.81
House finch	Passerine	Wind, Solar	0.1	0.3	0.387	0.05	0.29	0.47	0.507	0.04	0.42	0.58
Lesser nighthawk	Other	Solar	0.1	0.3	0.558	0.07	0.41	0.65	0.722	0.03	0.65	0.75
Mexican free-tailed bat	Bat	–	–	–	–	–	–	–	–	–	–	–
Mourning dove	Other	Wind, Solar	0.0	0.0	0.373	0.03	0.31	0.42	0.603	0.03	0.55	0.66
Red-necked phalarope	Waterbird	Solar	–	–	–	–	–	–	–	–	–	–
Red-tailed hawk	Raptor	Wind	0.0	0.0	0.504	0.15	0.24	0.75	0.795	0.02	0.76	0.83
Ruddy duck	Waterbird	Solar	–	–	–	–	–	–	–	–	–	–
Rufous hummingbird	Other	Solar	0.1	0.3	0.268	0.03	0.20	0.30	0.826	0.05	0.73	0.91
Swainson's hawk	Raptor	–	0.1	0.3	0.662	0.05	0.56	0.76	0.931	0.02	0.89	0.95
Tree swallow	Passerine	Solar	0.2	0.5	0.304	0.03	0.25	0.39	0.343	0.04	0.28	0.44
Tricolored blackbird	Passerine	–	0.2	0.5	0.521	0.05	0.41	0.60	0.772	0.02	0.73	0.80
Western grebe	Waterbird	Solar	0.0	0.0	0.204	0.06	0.10	0.35	0.920	0.02	0.87	0.95
Western meadowlark	Passerine	Wind, Solar	0.0	0.0	0.095	0.05	0.05	0.22	0.906	0.03	0.84	0.94
Western yellow-billed cuckoo	Passerine	–	0.2	0.5	0.421	0.05	0.29	0.49	0.665	0.05	0.56	0.76
White-crowned sparrow	Passerine	Solar	0.1	0.3	0.396	0.02	0.35	0.44	0.416	0.03	0.38	0.48
White-tailed kite	Raptor	Wind	0.1	0.3	0.329	0.06	0.23	0.42	0.883	0.04	0.80	0.94
Willow flycatcher	Passerine	–	0.1	0.3	0.446	0.05	0.39	0.56	0.848	0.03	0.80	0.91
Wilson's warbler	Passerine	Wind, Solar	0.2	0.5	0.355	0.05	0.27	0.44	0.433	0.02	0.40	0.46
Yellow warbler	Passerine	Solar	0.2	0.5	0.496	0.04	0.40	0.56	0.564	0.01	0.54	0.58
Yellow-rumped warbler	Passerine	Solar	0.0	0.0	0.454	0.02	0.41	0.48	0.511	0.03	0.47	0.56

Species guild, availability of δ^2H data collected at wind and solar facilities, constraints on prior distributions for survival (Φ) and fecundity (*fec*), model coefficients (±*SD*), and 95 percent credible intervals (CrI) for juvenile and adult survival demographic parameters estimated using integrated population models.

Source: U.S. Geological Survey

Results

The analysis presented here is preliminary and intended to meet reporting deadlines. Interested parties should consult the authors for final versions of this analysis.

The authors constructed IPM models for 29 of the 34 focal species (Table 8, Table 9). They excluded five species (black rail [*Laterallus jamaicensis*], red-necked phalarope, ruddy duck, hoary bat [*Lasiurus cinereus*], and Mexican free-tailed bat [*Tadarida brasiliensis*]) from subsequent analysis due to a complete lack of information for both population size and demographic parameters. There also were stable isotope data for 25 species. Two of these species (red-necked phalarope and ruddy duck) were not modeled because of the lack of demographic data. One species (common loon) was excluded from stable isotope analyses because δ^2H origin data were inconclusive due to marine influence. Thus, of the 29 species with built IPMs, stable isotope data were available for 22.

Table 9: Model Output for Demographic Parameters for 29 Species

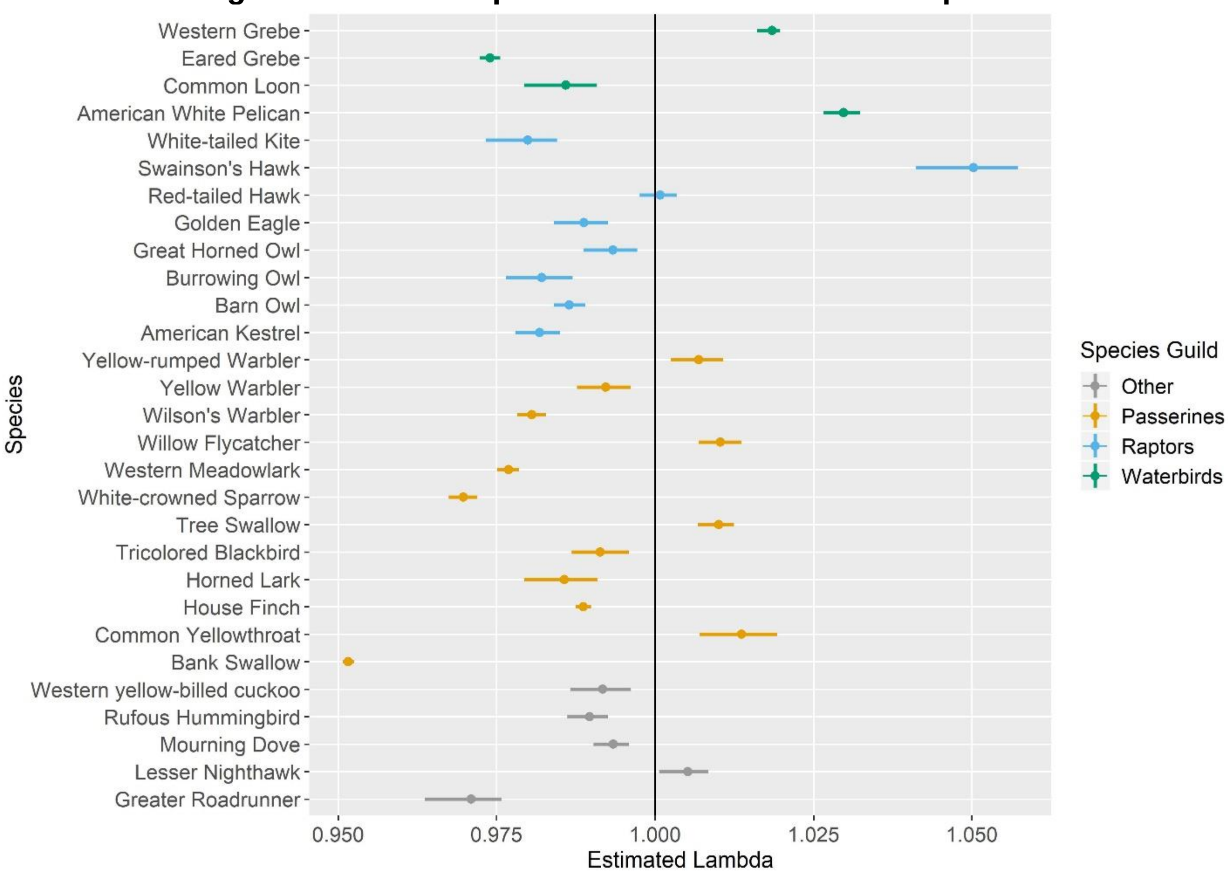
	Fecundity				Productivity				λ			
			95% CrI				95% CrI				95% CrI	
Species	**Estimate**	**SD**	**Lower**	**Upper**	**Estimate**	**SD**	**Lower**	**Upper**	**Estimate**	**SD**	**Lower**	**Upper**
American kestrel	1.098	0.23	0.67	1.56	0.216	0.08	0.12	0.32	0.982	0.002	0.978	0.985
American white pelican	0.458	0.03	0.39	0.51	0.339	0.09	0.28	0.38	1.030	0.002	1.027	1.032
Bank swallow	2.089	0.04	2.02	2.16	0.846	0.03	0.82	0.87	0.952	0.000	0.951	0.953
Barn owl	1.138	0.35	0.73	2.00	0.276	0.10	0.16	0.39	0.986	0.001	0.984	0.989
Burrowing owl	1.591	0.06	1.45	1.72	0.577	0.14	0.50	0.63	0.982	0.003	0.976	0.987
Common loon	0.743	0.12	0.52	0.98	0.596	0.15	0.42	0.79	0.986	0.003	0.979	0.991
Common yellowthroat	0.554	0.03	0.50	0.62	0.242	0.09	0.17	0.29	1.014	0.003	1.007	1.019
Eared grebe	0.851	0.09	0.74	1.06	0.125	0.07	0.09	0.17	0.974	0.001	0.972	0.976
Golden eagle	0.620	0.02	0.57	0.67	0.527	0.13	0.47	0.58	0.989	0.002	0.984	0.993
Great horned owl	0.638	0.08	0.53	0.85	0.644	0.15	0.53	0.77	0.993	0.002	0.989	0.997
Greater roadrunner	1.217	0.16	0.73	1.40	0.415	0.20	0.18	0.53	0.971	0.003	0.964	0.976
Horned lark	0.947	0.06	0.83	1.09	0.218	0.08	0.14	0.31	0.986	0.003	0.979	0.991
House finch	1.273	0.17	1.00	1.58	0.486	0.05	0.41	0.57	0.989	0.001	0.987	0.990
Lesser nighthawk	0.842	0.11	0.60	1.00	0.467	0.11	0.32	0.60	1.005	0.002	1.001	1.008
Mourning dove	0.975	0.04	0.89	1.04	0.364	0.07	0.30	0.42	0.993	0.001	0.990	0.996
Red-tailed hawk	0.993	0.37	0.49	1.84	0.458	0.13	0.28	0.68	1.001	0.001	0.998	1.003
Rufous hummingbird	0.935	0.10	0.71	1.08	0.250	0.08	0.18	0.31	0.990	0.002	0.986	0.993
Swainson's hawk	0.862	0.04	0.79	0.94	0.570	0.24	0.48	0.66	1.050	0.004	1.041	1.057
Tree swallow	2.817	0.35	2.04	3.31	0.846	0.07	0.76	0.90	1.010	0.001	1.007	1.012
Tricolored blackbird	0.402	0.04	0.32	0.47	0.209	0.06	0.17	0.26	0.991	0.002	0.987	0.996
Western grebe	0.438	0.02	0.41	0.47	0.089	0.05	0.04	0.15	1.018	0.001	1.016	1.020
Western meadowlark	0.791	0.21	0.43	1.23	0.070	0.03	0.04	0.14	0.977	0.001	0.975	0.979
Western yellow-billed cuckoo	0.921	0.13	0.64	1.12	0.387	0.14	0.24	0.51	0.992	0.002	0.987	0.996
White-crowned sparrow	1.913	0.11	1.61	2.03	0.756	0.06	0.66	0.81	0.970	0.001	0.967	0.972
White-tailed kite	1.082	0.11	0.96	1.36	0.299	0.11	0.20	0.40	0.980	0.003	0.973	0.985
Willow flycatcher	0.910	0.06	0.79	1.04	0.482	0.10	0.39	0.62	1.010	0.001	1.007	1.014
Wilson's warbler	2.168	0.33	1.65	2.79	0.753	0.06	0.67	0.82	0.981	0.001	0.978	0.983
Yellow warbler	1.358	0.13	1.10	1.58	0.670	0.08	0.57	0.76	0.992	0.002	0.988	0.996
Yellow-rumped warbler	1.011	0.11	0.80	1.22	0.459	0.08	0.36	0.55	1.007	0.002	1.002	1.011

Model coefficients (±*SD*) and 95 percent credible intervals (CrI) for fecundity, productivity, and λ estimated using integrated population models for 29 focal species.

Source: U.S. Geological Survey

Models suggested that 20 (69 percent) of the species with demographic models had a declining ($\lambda < 1$) mean population growth rate, while 9 species (31 percent) had a stable or positive ($\lambda \geq 1$) growth rate (Table 8;Table 9, Figure 20). Almost all raptors and small birds had $\lambda < 1$. However, 4 of 12 passerines (common yellowthroat [*Geothlypis trichas*], yellow-rumped warbler [*Setophaga coronata*], tree swallow [*Tachycineta bicolor*], and willow flycatcher [*Empidonax traillii*]), 2 waterbirds (western grebe and American white pelican [*Pelecanus erythrorhynchos*]), and 1 raptor (Swainson's hawk [*Buteo swainsoni*]) had $\lambda \geq 1$.

Figure 20: Mean Population Growth Rate for 29 Species

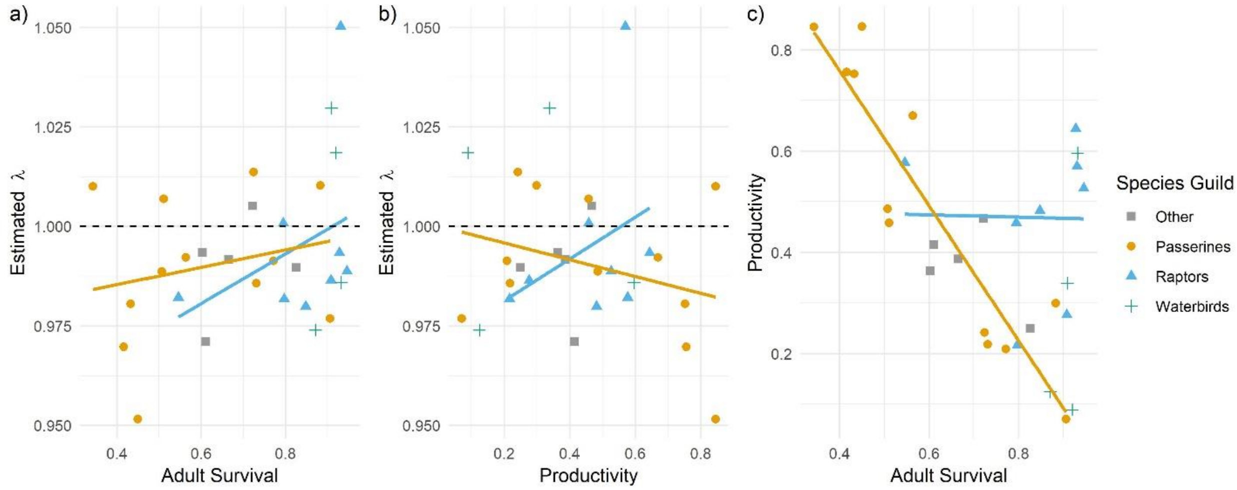


Geometric mean of population growth rate (λ) and 95 percent CrI (lines) for 29 focal species based on Breeding Bird Survey annual indices from 1968–2015, based on species group. A value of λ = 1 (black line) indicates a stable population.

Source: U.S. Geological Survey

In general, λ was positively related to adult survival (Figure 21a). In contrast, there were guild-specific differences in how λ responded to productivity (the product of juvenile survival and fecundity). Productivity of passerines declined for species with greater λ, while raptor species with higher productivity also experienced increased population growth (Figure 21b). Additionally, there was a strong negative relationship between adult survival and productivity, but only for passerines (Figure 21c).

Figure 21: Adult Survival, Productivity, and Population Growth Rate for 29 Species

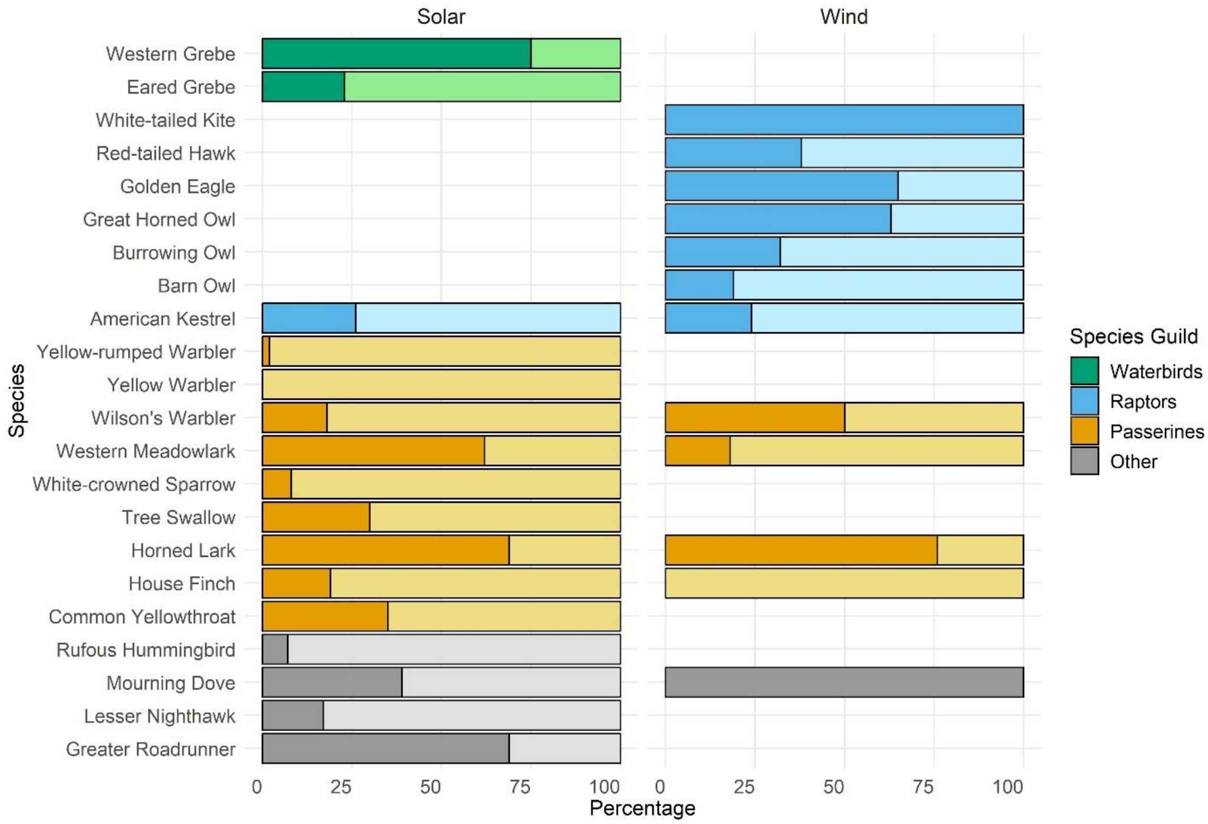


Model estimates for a) adult survival and b) productivity (juvenile survival x fecundity) versus estimated population growth rate (*λ*) and c) adult survival versus productivity for 29 focal species. Linear trend lines are shown for passerine (orange) and raptor (blue) species guilds. Dashed horizontal lines in a) and b) correspond to a stable population growth rate (*λ* = 1).

Source: U.S. Geological Survey

For the 22 species for which there were both models and isotope data (Table 8), it was possible to estimate the proportion of individuals killed at wind (*n* = 12) and solar (*n* = 16) facilities that were of local origin. Seven raptor species comprised the majority of samples at wind facilities (primarily collected at APWRA), while samples from solar facilities included only one raptor (American kestrel) but two species of waterbirds and multiple passerines (Figure 22; Table 5, Table 6). Six species were killed at both types of facilities.

Figure 22: Local and Nonlocal Individuals Killed at Renewable Energy Facilities

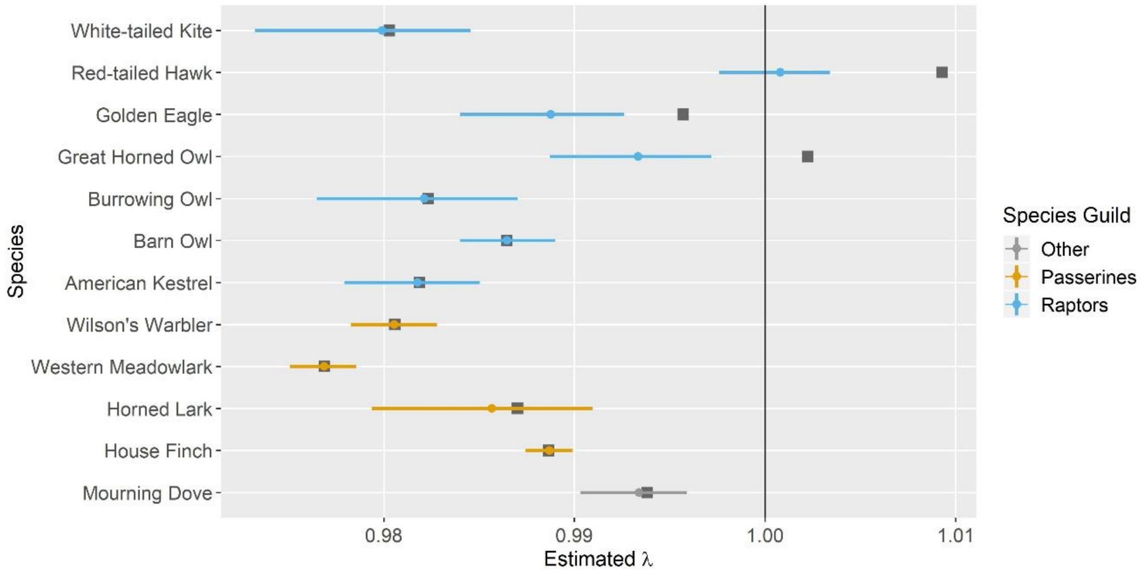


Percent of individuals killed at solar and wind renewable energy facilities assigned to local (dark) and nonlocal (light) geographic origins based on feather δ^2H values by species guild (raptors, waterbirds, passerines, and other small birds) for 22 avian species with compiled integrated population models.

Source: U.S. Geological Survey

Of species with isotope data that were killed at wind facilities, 92 percent had λ less than 1 (Table 8; Figure 23). Only one species (red-tailed hawk) had a λ greater than 1, but the 95 percent credible interval (CrI; the interval within which the parameter value falls with a 95 percent probability) for that estimate overlapped 1 (β = 1.001, 95 percent CrI: 0.998, 1.003). In contrast, of species with isotope data killed at solar facilities, five (31 percent; western grebe, lesser nighthawk [*Chordeiles acutipennis*], common yellowthroat, yellow-rumped warbler, and tree swallow) had λ greater than 1 (Table 8; Figure 24).

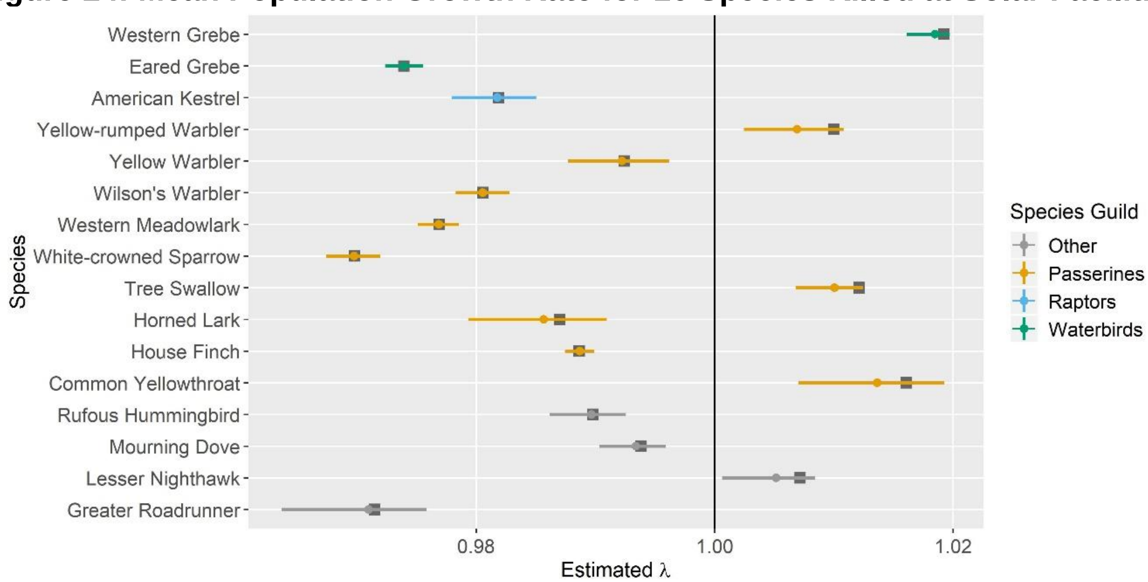
Figure 23: Mean Population Growth Rate for 12 Species Killed at Wind Facilities



Geometric mean and 95 percent credible intervals (CrI; lines) for population growth rate (*λ*) derived from integrated population models for 12 avian species killed at wind facilities with associated stable isotope data (see Chapter 5). Dark gray squares represent the geometric mean of species-specific BBS annual indices from 1968–2015 data used in the model relative to derived model estimates. The black line at *λ* = 1 indicates a stable population.

Source: U.S. Geological Survey

Figure 24: Mean Population Growth Rate for 16 Species Killed at Solar Facilities

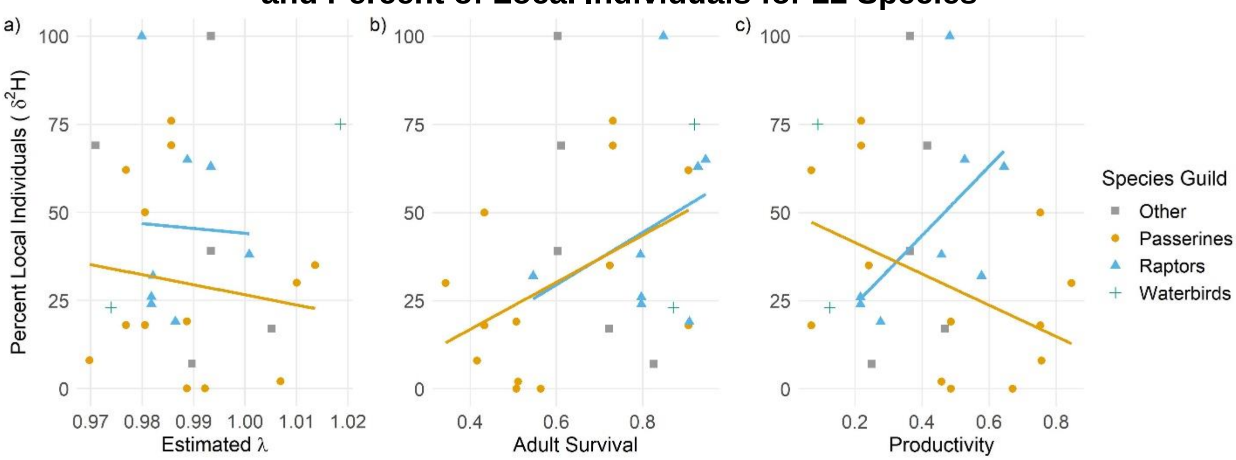


Geometric mean and 95 percent credible intervals (CrI; lines) for population growth rate (*λ*) derived from integrated population models for 16 avian species killed at solar facilities with associated stable isotope data (see Chapter 5). Dark gray squares represent the geometric mean of species-specific BBS annual indices from 1968-2015 data used in the model relative to derived model estimates. The black line at *λ* = 1 indicates a stable population.

Source: U.S. Geological Survey

There were differences in λ, adult survival, and productivity relative to the proportion of local individuals between species guilds and across renewable energy types. For example, trendlines suggested that species for which individuals killed were predominantly local may have lower population growth (Figure 25a). The exception to this trend was the two waterbird species (eared grebe and western grebe). The proportion of local individuals was greater for species with greater adult survival for both passerines and raptors, while the opposite trend was observed for other nonpasserine species, including greater roadrunner, rufous hummingbird, lesser nighthawk, and mourning dove (*Zenaida macroura*; Figure 25b). Conversely, the relationship between estimated productivity and proportion of local individuals differed between raptors and passerines (Figure 25c). The proportion of local individuals declined for passerines with greater productivity, but increased for raptors, suggesting that raptor species may benefit from dominant individuals returning to breeding grounds, as these older birds may produce more surviving offspring per individual than nonlocal immigrants. The reverse is true for passerines that typically have lower adult survival and may be more reliant on immigrants to sustain local populations.

Figure 25: Adult Population Growth Rate, Survival, Productivity, and Percent of Local Individuals for 22 Species



Model estimates for a) population growth (λ), b) adult survival, and c) productivity (juvenile survival x fecundity) versus the proportion of individuals killed at renewable energy facilities classified as local individuals for 22 focal species with integrated population models and associated δ^2H data. Linear trend lines are shown for passerine (orange) and raptor (blue) species guilds.

Source: U.S. Geological Survey

Discussion

Interpreting Demographic Models

By incorporating data and prior information from multiple datasets, the authors were able to estimate basic demographic parameters for multiple species affected by renewable energy facilities. The authors' approach is new in part because of the lack of robust demographic data for so many of the species whose populations were modeled. However, by incorporating informative priors (when available) within the modeling framework, the authors were able to incorporate pre-existing knowledge about other populations.

The results highlighted differences in demographic parameters and population growth among species adversely affected by renewable energy production. These differences may be due to differences in life history strategies (MacArthur and Wilson 1967). For example, almost all of the modeled raptor species, except for Swainson's hawks, had declining populations in California (Figure 20). Raptors are avian predators commonly classified as *k-selected* species with relatively stable populations (high adult survival), delayed age at first breeding (for example, greater than 2 to 4 years old), and low reproductive output. It is established that *k*-selected species are more vulnerable to anthropogenic impacts that influence survivorship, so it is not surprising that these species were particularly vulnerable. In contrast, passerines and other small-bodied songbirds are *r-selected* species with lower adult survival, rapid maturity (that is, age at first breeding less than 1 year old), and large clutch sizes. These species may be less vulnerable to threats from renewable energy that cause changes to individual survivorship. In contrast, threats that remove or alter breeding success (for example, a solar facility that destroys acres of habitat) may be more relevant to species with such a life history.

The results suggested that population growth rate, λ, was positively related to adult survival for all species guilds, especially for raptors (Figure 21a). The population growth rate of many avian species is relatively more sensitive to small changes in adult survival than to changes in any other parameter. This is especially true for species with higher adult survival rates. In contrast, reproductive parameters may be more important for determining λ in *r*-selected species such as passerines (Figure 21b; Sæther and Bakke 2000; Stahl and Oli 2006). The results were consistent with this scenario, as population growth rate tended to be higher for raptor species with greater productivity, but the linear trend line suggested a three-time increase in productivity was necessary to produce the same increase in estimated population growth rate as a 1.7-time increase in adult survival (for example, 0.55 to 0.95). In contrast, the results suggested productivity was lower for passerines with higher population growth rate values, but this trend was primarily driven by the strong negative relationship between passerine productivity and adult survival (Figure 21c). It is also important to note that even though population growth rates increased with increasing adult survival, only 31 percent of the 29 species evaluated had positive population growth rate values. Thus, having high adult survival may not be enough on its own to maintain stable populations in a human-dominated landscape, especially if there are not corresponding increases in fecundity or juvenile survival.

Additionally, patterns in the relationships between the proportion of local individuals and population growth rate, adult survival, and productivity, respectively, further suggest the importance of considering both species-specific life history traits and site-specific risk to populations. The authors noted an increase in the proportion of local individuals relative to increased adult survival for passerines and raptor species (Figure 25b).

This relationship between productivity and proportion of local individuals in passerines suggests it is important to consider the regional- and continental-scale effects to migrant and nonbreeding wildlife populations. It also highlights the importance of managing for both local and nonlocal populations, especially for migratory species. In general, avian protection plans for renewable energy facilities focus primarily on local breeding populations of large birds with high adult survival and low fecundity (for example, raptors and waterbirds) and species of conservation concern. These analyses indicate that those plans will be more accurate if they consider impacts to populations of species distant from the facility itself.

Limitations to the Modeling Approach

The authors' demographic models also highlighted the limited data on year-round and site-specific population estimates and demographic parameters for many birds and bats, including the majority of the focal species. Understanding the interactive effects of migratory connectivity, breeding and wintering habitat, and state-specific survival and fecundity estimates on population dynamics is important, especially for migrating species (Marra et al. 2015; Oberhauser et al. 2017; Rushing et al. 2017). However, determining the potential threats of renewable energy on wildlife populations is difficult when these demographic data are missing or inaccessible (Frick et al. 2017).

While large-scale multiyear datasets are available through monitoring programs such as BBS, data are limited to the breeding period. Similarly, the MAPS program (DeSante, Kaschube, and Saracco 2015) conducts demographic monitoring through mist-netting efforts, but inference is restricted to approximately 150 North American passerines. Additional taxon-specific counts for migratory birds, waterfowl, and raptors, and citizen science efforts including Christmas Bird Counts (National Audubon Society 2010) and eBird (Sullivan et al. 2009), provide information on wintering birds and year-round observations, respectively, but data availability depends on observer and survey effort. As such, there is no encompassing year-round dataset that provides information on population dynamics across seasons for the majority of North American birds. In spite of these limitations, these models are important because they are a first attempt to generate parameter estimates for these species using Bayesian models that deal well with uncertainty. They also highlight some of the challenges of preparing models for a large group of species, and they serve to increase the focus on key demographic parameters needed for future conservation and impact mitigation efforts.

Conclusions

Interpreting demographic models within the context of the overall potential effects of renewable energy-related fatalities on wildlife populations depends on the confluence of multiple factors in addition to the current population growth rate (λ). Other essential components include the size and geographic range of the extant population and the size of the catchment area adversely affected by renewable energy (for example, the proportion of nonlocal individuals in the population estimated from the δ^2H data [also see Chapter 5]). For illustration purposes, mourning doves, a generalist gamebird with a range extending across North America and an estimated population of 243 million (Seamans 2018), have a near-stable population growth rate (β = 0.993, 95 percent CrI: 0.990, 0.996). Additionally, all (n = 6) mourning dove δ^2H samples from wind facilities and 39 percent (n = 41) from solar facilities were classified as local individuals. As such, additional fatalities from wind and solar facilities are likely to have little influence on the stability of the population. In contrast, golden eagles are a large raptor with an estimated North American population of 40,000 (Millsap et al. 2016), declining population growth rate (β = 0.989, 95 percent CrI: 0.984, 0.993), and a large catchment area (for example, 35 percent of stable isotope individuals classified as nonlocal). Additional eagle fatalities from renewable energy may have a greater negative effect on both the local and continental-scale population. Additionally, if the species of interest has a restricted geographic range (for example, white-tailed kites [*Elanus leucurus*], a medium-small hawk found primarily in central California, south Texas, and Mexico), added fatalities may be highly influential on the population, regardless of the current population size and growth rate.

All that said, there are a few general patterns about risk that can be drawn from these modeling efforts. In general, species with lower adult survival appear to be, across the board, at greater risk from renewable energy generation. This is unexpected because many of these species are *r*-selected and should not be as vulnerable to increases in mortality rate. However, the relationship between reproductive output and risk is more complex and guild-specific.

Future analyses will incorporate these demographic model results along with the stable isotope data and population size estimates to predict the number of fatalities a population in a given region can sustain at that current population growth rate. By estimating the maximum total fatalities acceptable to maintain an existing λ value, researchers and managers can compare these estimates with fatality estimates from renewable facilities for a given region and determine if the number of individuals killed at wind and solar facilities exceed the total fatality estimates.

CHAPTER 7: Technology/Knowledge Transfer Activities

This project created a series of specific knowledge products and transfer activities. This work did not create technology or markets for transfer, so there were no products or activities in this regard.

Knowledge Products the Project Created

The specific knowledge products created through this project, and the chapters of the report in which they appear, include:

- Creation of a set of recommendations to standardize pre- and post-construction and pre- and post-mitigation surveys at renewable energy facilities within California (chapters 2 and 3).
- Identification and implementation of tools to assess the geographic and, thus, demographic scope of fatalities at renewable energy facilities in California (Chapter 4).
- Identification of a suite of species well-suited to assessment of population-level effects of renewable-energy-caused fatalities within California and characterization of the population subset affected and the demographic effects of those fatalities (chapters 5 and 6).
- Identification of a suite of species for which a present lack of understanding makes population-level assessment difficult or impossible; the authors identified such species as high priorities for future research as a basis for future assessment (Chapter 6; these are the species for which there were too little data to build models or for which models performed poorly).

Knowledge Transfer Activities From this Project

A number of knowledge transfer activities resulted from this project, including:

- One-on-one meetings with public and key decision-makers.
  - These occurred regularly throughout the course of this project, in phone calls, on the sidelines at conferences, and in other settings.
- Workshops with energy developers, the public, and decision-makers.
  - In January 2018, Principal Investigator Katzner presented a seminar/workshop on results of this project to the American Wind Wildlife Institute and its industry partners.

    - Results of this work have been drawn upon during meetings of the technical advisory committee for Alameda County that advises the county on wind power issues.
- Presentations at scientific meetings (examples below), local citizens' groups, and town and county meetings.

Work supported by this project resulted in a large number of presentations. Some of these were:

- Conkling, Tara, Todd Katzner, Jay Diffendorfer, Julie Yee, Hannah Vander Zanden, David Nelson, Scott Loss, and Adam Duerr. 2018. "Demography of Birds Killed at Wind Facilities." St. Paul, MN: Wind Wildlife Research Meeting. Oral presentation.
- Vander Zanden, Hannah B., David M. Nelson, Tara J. Conkling, and Todd E. Katzner. 2018. "A Wildlife Forensics Approach to Characterize the Geographic Footprint of California Wind Energy Effects on Avian Populations." St. Paul, MN: Wind Wildlife Research Meeting. Oral presentation.
- Katzner, Todd E., Tara Conkling, Scott Loss, Taber Allison, Jay Diffendorfer, and Adam Duerr. 2018. "Assessing Standardization in Studies of Wind Energy Impacts on Birds and Bats." St. Paul, MN: Wind Wildlife Research Meeting. Oral presentation.
- Vander Zanden, Hannah B., David M. Nelson, Tara J. Conkling, and Todd E. Katzner. 2018. "The Geographic Extent of Solar Energy Effects on California Avian Populations." Viña del Mar, Chile: International Conference on Applications of Stable Isotope Techniques to Ecological Studies.
- Reid, Abigail M., Hannah B. Vander Zanden, Todd E. Katzner, and David M. Nelson. 2018. "The Implications for Using Singed Feathers in Determining Geographic Origin with Wildlife Forensics Approaches." Chattanooga, TN: Association of Field Ornithologists (AFO) and Wilson Ornithological Society Joint Meeting. Received AFO student award.
- Conkling, Tara J., Hannah B. Vander Zanden, Jay E. Diffendorfer, Adam E. Duerr, Scott R. Loss, David M. Nelson, and Todd E. Katzner. 2018. "Demography of Birds Killed at Solar Energy Facilities." Tucson, AZ: American Ornithology Society Annual Meeting.
- Vander Zanden, Hannah B., David M. Nelson, Tara J. Conkling, and Todd E. Katzner. 2018. "The Geographic Footprint of California Solar Energy Effects on Bird Populations." Tucson, AZ: American Ornithology Society Annual Meeting.
- Katzner, Todd E., and Tara Conkling. 2017. "Effects of Renewable Energy Development on Wildlife." Sacramento, CA: Technical Symposium on Avian-Solar Interactions.

Work supported by this project has already resulted in several peer-reviewed publications, including:

- Vander Zanden, Hannah B., David M. Nelson, Michael B. Wunder, Tara J. Conkling, and Todd Katzner. 2018. "Application of Isoscapes to Determine Geographic Origin of Terrestrial Wildlife for Conservation and Management." *Biological Conservation* 228: 268–280.
- Vander Zanden, Hannah B., Abigail Reid, Todd Katzner, and David M. Nelson. 2018. "Effect of Heat and Singeing on Stable Hydrogen Isotope Ratios of Bird Feathers and Implications for Their Use in Determining Geographic Origin." *Rapid Communications in Mass Spectrometry* 32:1859–1866.
- Conkling, Tara J., Scott R. Loss, Taber D. Allison, Jay E. Diffendorfer, Adam Duerr, Julie Yee, and Todd E. Katzner. *In review*. "Limitations, Lack of Standardization, and Recommended Best Practices in Studies of Renewable Energy Effects on Birds and Bats."

CHAPTER 8: Conclusions and Recommendations

This project produced five California-specific products, one each on standardization of studies of renewable energy impacts on wildlife (Chapter 2), on mitigation practices at renewable energy facilities (Chapter 3), on development of tools to identify the geographic origin of wildlife killed at renewable energy facilities (Chapter 4), on identification of those geographic origins (Chapter 5), and on population biology of those affected species (Chapter 6).

Standardization of Studies of Renewable Energy Impacts on Wildlife (Chapter 2)

Several key conclusions about renewable energy production in California can be drawn from this product:

- Post-construction monitoring for wildlife mortality is the norm at renewable energy facilities.
- Pre-construction monitoring is much less frequent and, when it occurs, is almost never designed to assess mortality rates.
- For at least half of renewable energy facilities in California, the authors were unable to find evidence of both pre- and post-construction monitoring.
- When surveys are conducted, either pre- or post-construction, only some of the time are they accompanied by a description of an experimental design.
- Habitat use surveys rarely incorporate detection rates.
- Reporting of wildlife surveys is not consistent, and only some reports are publicly visible.
- As a consequence of these weaknesses, it is almost impossible to make reasonable comparison among surveys, either over time (for example, pre- vs. post-construction) or over space (that is, among facilities).

Since comparisons over time and space are essential for managers, there are some obvious ways to improve the science of wildlife surveys at renewable energy facilities. Improvement of this science would provide value to managers who wish to implement conservation action and to ratepayers who wish to understand true impacts to wildlife of energy generation. The science of wildlife surveys at energy facilities would be improved by:

- Implementation of both pre- and post-construction surveys for wildlife.
- Standardization of surveys over time and space (that is, conduct the same surveys pre- and post-construction and at each facility).

- Implementation of high-quality and standardized experimental design in surveys.
- Incorporation of detection rates into all types of surveys and, for mortality surveys, of carcass removal rates.
- Aggregation of reporting into a central database that would allow more effective comparison and scientific study of effects to wildlife from renewable energy facilities.

Mitigation Practices at Renewable Energy Facilities (Chapter 3)

Mitigation is less frequently reported at renewable energy facilities than are pre- and post-construction surveys. This may reflect a lack of implementation of mitigation activities. However, because most reports are focused on pre- and post-construction surveys, it is possible that mitigation activities were simply not reported. Nonetheless, the recommendations for improvement of the science around mitigation activities are nearly identical to those for wildlife surveys. Specifically, implementation of pre- and post-mitigation surveys with an experimental design, standardization of those surveys, incorporation of detection rates, and aggregation into a central database would all allow for improvements to the science of mitigation and of evaluation of its impacts. These benefits would especially prove helpful to managers who make decisions about if and when to implement mitigation activities.

Development and Implementation of Tools to Identify Region of Origin of Wildlife Affected by Renewable Energy Facilities (Chapters 4 and 5)

This section detailed a conceptual framework and one tool to identify the origins of wildlife affected by renewable energy generation and illustrated this approach by implementing it for wildlife killed at wind and solar energy facilities. A number of conclusions about the scientific framework can be drawn for this approach:

- To understand the impact of renewable energy generation to wildlife population persistence, it is essential to know where affected wildlife originated, that is, to which population they belong.
- Intrinsic markers, such as hydrogen stable isotope composition, provide a useful mechanism to obtain this knowledge.
- This study identified a number of best practices that can be employed when conducting stable isotope analysis to identify origins of wildlife.

Likewise, there are several conclusions about the implementation of the approach:

- The majority of individuals of all species killed at both wind and solar facilities are well suited for hydrogen isotope analysis.

- From 24 percent to 100 percent of individuals killed at renewable energy facilities were nonlocal in origin (they grew their feathers far from the site where they died).
- Migration periods (spring and fall) corresponded with times when relatively higher proportions of individuals were nonlocal in origin.
- The ratio of local to nonlocal individuals killed of a given species was not always the same between wind and solar facilities, suggesting that these two energy generation systems may, for some species, affect different source populations.
- A large proportion of the wildlife killed at renewable energy facilities in the state were nonlocal and predominantly from outside California.

From a scientific perspective, if managers wish to understand effects of renewable energy on wildlife, they must understand where the affected wildlife are from. Using a tool such as stable hydrogen isotope analysis in the context of the best practices outlined in this report is one useful approach to obtain this knowledge. In the case of the renewable energy facilities within California sampled here, when assessing impacts to wildlife populations, it is important to consider effects not only within the state but also well beyond the state borders.

Population Biology of Affected Species (Chapter 6)

Several key conclusions can be drawn from the population modeling conducted in this section of the report:

- Understanding effects to wildlife from renewable energy is improved by some type of population modeling.
- Much of the species-specific data required for population modeling are either missing or highly variable. Bayesian tools are one useful way to use imprecise data to incorporate the uncertainty in population estimates.
- Incorporating information on the origin of individuals is useful in increasing the relevance of models based on uncertain data.
- Building demographic models for a large suite of species presents special challenges that go beyond those required of models for a single species.
- Populations of most species considered here were declining.
- Of the species killed, those of predominantly local origin were especially likely to have lower population growth rates (that is, they were declining) and greater adult survival (that is, they were long-lived species).

These conclusions suggest several recommendations:

- It would be useful to collect more baseline biological and natural history information for many species affected by fatalities at renewable energy facilities. Such data may include not only information about reproduction but also about migration and origins of animals that pass through California.

- Use of Bayesian population models may be one way to address some limitations in information, but even these models are limited by data availability.
- Wildlife populations distant from California were affected by fatalities at renewable energy facilities within the state. Scientific evaluation of the relevance of wildlife fatalities to specific species should consider the effects to both populations within California and populations distant from California, as significant effects were observed in both.

Chapter 9: Benefits to Ratepayers

This project produced a number of benefits to ratepayers, with respect to EPIC goals of greater reliability, lower costs, and increased safety. These benefits can be quantitative, in both general and specific terms, and qualitative.

From a general perspective, consistency of energy generation can be influenced by costly approaches to environmental management (for example, turbine curtailment when protected species are present). Furthermore, costs are determined in part by the number of compliance requirements and efficiency of compliance with environmental regulations. Finally, safety of energy production and distribution infrastructure are affected by wildlife (for example, birds can cause damage to infrastructure, increasing the likelihood of fire, and curtailment can increase wear on turbines, increasing accident and injury rates). Ultimately, these factors interact because effective understanding of the impacts to wildlife from renewable energy generation can streamline environmental permitting management, improving reliability and cost. Likewise, this same understanding allows streamlining compliance efforts, which reduces costs, and targeting of infrastructure-wildlife mitigation effort, which improves safety. This project benefits ratepayers in all these regards.

Specifically, this project provides a framework and specific tools for understanding environmental impacts of renewable energy generation. The approach taken here—improving field surveys to estimate the actual numbers of wildlife affected by renewable energy generation, estimating the catchment area of origin of wildlife, and then using population models to understand dynamics of those populations—is a framework that others can use to achieve similar goals. Likewise, the specific tools—stable isotope analysis to identify a catchment area and Bayesian population models of wildlife in those areas—provide a starting point for future work in this area.

Finally, this project has numerous benefits to California investor-owned utility ratepayers. It provides a context to refine predictions associated with infrastructure development, energy production, and environmental change. Likewise, it outlines tools that can be used to provide increased certainty in the regulatory atmosphere for developers and ratepayers. Reduced uncertainty facilitates development and even compliance, for example in meeting USFWS management requirements (such as no net loss) and California Environmental Quality Act objectives. Finally, many ratepayers value the reduction of environmental impacts of energy generation, and this project provides one approach to minimizing those impacts.

GLOSSARY AND LIST OF ACRONYMS

Term/Acronym	Definition
APWRA	Altamont Pass Wind Resource Area
AWWI	American Wind Wildlife Institute
BACI	Before-After Control-Impact study
BBS	North American Breeding Bird Survey
BBS annual index estimates	Interannual change in the mean number of individuals per stratum in North American Breeding Bird Surveys
breeding site survey	Survey method used by facilities, such as nest searching
CASIF	Central Appalachians Stable Isotope Facility, at the University of Maryland Center for Environmental Science's Appalachian Laboratory
catchment area	Geographic area from which individuals killed at wind and solar energy facilities originate
CrI	credible interval; the interval within which the parameter value falls with a 95 percent probability
facility	Wind or solar facility name in each report
growing season (GS)	Precipitation isoscape that integrates long-term isotopic data within the growing season
IPM	integrated population model
IsoMAP	An online workspace that allows users to implement models for isotope distributions
k-selected	Species that have high adult survival, slow maturity, and low reproductive output
local	The likely region of geographic origin of birds killed at renewable energy facilities is close to the facility
MAPS	Monitoring Avian Productivity and Survivorship
mean-annual (MA)	Precipitation isoscape that integrates long-term isotopic data across the entire year
nonidentifiability	The situation when multiple combinations of demographic model parameters can result in the same λ value

Term/Acronym	Definition
nonlocal	The likely region of geographic origin of birds killed at renewable energy facilities is far from the facility
PBR	potential biological removal
population size estimation	Survey method used by facilities, such as a point count for birds
r-selected	Species that have low adult survival, rapid maturity, and high reproductive output
rescaling function	A linear regression relationship between tissue values and values in the baseline precipitation isoscape
reports	Peer-reviewed literature and unpublished reports containing pre- and post-construction wildlife survey data from proposed and operating wind and solar facilities
subunit	Smaller unit within a wind or solar facility
taxon or status-specific survey	Survey method used by facilities, such as a survey for a specific species
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

REFERENCES

American Wind Wildlife Institute (AWWI). 2017. *AWWIC Documents Library*. Washington, DC: AWWI. https://awwic.nacse.org

Argonne National Laboratory and National Renewable Energy Laboratory. 2015a. *A Review of Avian Monitoring and Mitigation Information at Existing Utility-Scale Solar Facilities.* Prepared for U.S. Department of Energy, SunShot Initiative and Office of Energy Efficiency & Renewable Energy. http://www.evs.anl.gov/downloads/ANL-EVS_15-2.pdf

Argonne National Laboratory and National Renewable Energy Laboratory. 2015b. *Bibliography of Literature for Avian Issues in Solar and Wind Energy and Other Activities*. Prepared for U.S. Department of Energy, SunShot Initiative and Office of Energy Efficiency & Renewable Energy. https://www.procon.org/sourcefiles/argonne-national-laboratory-2015.pdf

Arnett, Edward B. 2006. "A Preliminary Evaluation on the Use of Dogs to Recover Bat Fatalities at Wind Energy Facilities." *Wildlife Society Bulletin* 34:1440–1445.

Arnett, Edward B., and Erin F. Baerwald. 2013. "Impacts of Wind Energy Development on Bats: Implications for Conservation." In *Bat Evolution, Ecology, and Conservation*, eds. Rick A. Adams and Scott C. Pedersen, 435–456. New York: Springer Science+Business Media.

Arnett, Edward B., Manuela M.P. Huso, Michael R. Schirmacher, and John P. Hayes. 2011. "Altering Turbine Speed Reduces Bat Mortality at Wind-Energy Facilities." *Frontiers in Ecology and the Environment* 9:209–214.

Arnett, Edward B., Gregory D. Johnson, Wally P. Erickson, and Cris D. Hein. 2013. *A Synthesis of Operational Mitigation Studies to Reduce Bat Fatalities at Wind Energy Facilities in North America*. Prepared for The National Renewable Energy Laboratory. Austin, TX: Bat Conservation International. https://docs.wind-watch.org/Synthesis-Operational-Mitigation-Studies.pdf

Arnett, Edward B., and Roel F. May. 2016. "Mitigating Wind Energy Impacts on Wildlife: Approaches for Multiple Taxa." *Human–Wildlife Interactions* 10:28–41.

Asante, Christian K., Timothy D. Jardine, Steven L. Van Wilgenburg, and Keith A. Hobson. 2017. "Tracing Origins of Waterfowl Using the Saskatchewan River Delta: Incorporating Stable Isotope Approaches in Continent-Wide Waterfowl Management and Conservation." *The Condor* 119:261–274.

Badyaev, Alexander V., Virginia Belloni, and Geoffrey E. Hill. 2012. "House Finch (*Haemorhous mexicanus*), version 2.0." In *The Birds of North America*, ed. A.F. Poole. Ithaca, NY: Cornell Lab of Ornithology. https://doi.org/10.2173/bna.46

Baerwald, Erin F., Jason Edworthy, Matt Holder, and Robert M.R. Barclay. 2009. "A Large-Scale Mitigation Experiment to Reduce Bat Fatalities at Wind Energy Facilities." *Journal of Wildlife Management* 73:1077–1081.

Besbeas, P., S.N. Freeman, B.J.T. Morgan, and E.A. Catchpole. 2002. "Integrating Mark–Recapture–Recovery and Census Data to Estimate Animal Abundance and Demographic Parameters." *Biometrics* 58:540–547.

Biosystems Analysis, Inc. and IBIS Environmental Services. 1996. *Effects of Wind Energy Development: An Annotated Bibliography*. Wind-Wildlife Impacts Literature Database, National Renewable Energy Laboratory. https://wild.nrel.gov/node/1201

BirdLife International and Handbook of the Birds of the World. 2016. *Bird Species Distribution Maps of the World*, version 6.0. http://datazone.birdlife.org/species/requestdis

Birds of North America. 2015. Birds of North America web site, ed. Paul Rodewald. Ithaca, NY: Cornell Laboratory of Ornithology. https://birdsna.org

Bond, Alexander L., and Keith A. Hobson. 2012. "Reporting Stable-Isotope Ratios in Ecology: Recommended Terminology, Guidelines and Best Practices." *Waterbirds* 35:324–331.

Bortolotti, Lauren E., Robert G. Clark, and Leonard I. Wassenaar. 2013. "Hydrogen Isotope Variability in Prairie Wetland Systems: Implications for Studies of Migratory Connectivity." *Ecological Applications* 23:110–121.

Bowen, Gabriel J. 2010. "Statistical and Geostatistical Mapping of Precipitation Water Isotope Ratios." In *Isoscapes: Understanding Movement, Pattern, and Process on Earth Through Isotope Mapping*, eds. Jason B. West, Gabriel J. Bowen, Todd E. Dawson, and Kevin P. Tu, 139–160. New York: Springer Science+Business Media.

Bowen, Gabriel J., Zhongfang Liu, Hannah B. Vander Zanden, Lan Zhao, and George Takahashi. 2014. "Geographic Assignment with Stable Isotopes in IsoMAP." *Methods in Ecology and Evolution* 5:201–206.

Bowen, Gabriel J., and Justin Revenaugh. 2003. "Interpolating the Isotopic Composition of Modern Meteoric Precipitation." *Water Resources Research* 39:1299.

Bowen, Gabriel J., Leonard I. Wassenaar, and Keith A. Hobson. 2005. "Global Application of Stable Hydrogen and Oxygen Isotopes to Wildlife Forensics." *Oecologia* 143:337–348.

Bowen, G.J., J.B. West, C.C. Miller, L. Zhao, and T. Zhang. 2018. *IsoMAP: Isoscapes Modeling, Analysis and Prediction (version 1.0)*. The IsoMAP Project. http://isomap.org

Bowen, Gabriel J., Jason B. West, Bruce H. Vaughn, Todd E. Dawson, James R. Ehleringer, Marilyn L. Fogel, Keith Hobson, Jurian Hoogewerff, Carol Kendall, Chun-Ta Lai, C.C. Miller, David Noone, Henry Schwarcz, and Christopher J. Still. 2009. "Isoscapes to Address Large-Scale Earth Science Challenges." *Eos* 90:109–110.

Brennan, Sean R., and Daniel E. Schindler. 2017. "Linking Otolith Microchemistry and Dendritic Isoscapes to Map Heterogeneous Production of Fish Across River Basins." *Ecological Applications* 27:363–377.

Brennan, Sean R., Christian E. Zimmerman, Diego P. Fernandez, Thure E. Cerling, Megan V. McPhee, and Matthew J. Wooller. 2015. "Strontium Isotopes Delineate Fine-Scale Natal Origins and Migration Histories of Pacific Salmon." *Science Advances* 1:e1400124.

Bridge, Eli S., Jeffrey F. Kelly, Andrea Contina, Richard M. Gabrielson, Robert B. MacCurdy, and David W. Winkler. 2013. "Advances in Tracking Small Migratory Birds: A Technical Review of Light-Level Geolocation." *Journal of Field Ornithology* 84:121–137.

Briggs, Christopher W., Simon R. Poulson, and Michael W. Collopy. 2017. "Correlation Between Feather Isotopes and Body Condition for Swainson's Hawks, and Implications for Migration Studies." *Journal of Raptor Research* 51:107–114.

Britzke, Eric R., Susan C. Loeb, Keith A. Hobson, Christopher S. Romanek, and Maarten J. Vonhof. 2009. "Using Hydrogen Isotopes to Assign Origins of Bats in the Eastern United States." *Journal of Mammalogy* 90:743–751.

Brooks, S.P., R. King, and B.J.T. Morgan. 2004. "A Bayesian Approach to Combining Animal Abundance and Demographic Data." *Animal Biodiversity and Conservation* 27.1:515–529.

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas. 2001. *Introduction to Distance Sampling*. New York: Oxford University Press.

California Energy Commission (CEC). 1989. *Avian Mortality at Large Wind Energy Facilities in California: Identification of a Problem*. Sacramento, CA: CEC.

California Energy Commission (CEC). 2010. *Genesis Solar Energy Project: Commission Decision*. CEC-800-2010-011 CMF. Sacramento, CA: CEC. https://www.energy.ca.gov/2010publications/CEC-800-2010-011/CEC-800-2010-011-CMF.pdf

California Energy Commission (CEC). 2017. *Alphabetical List of Power Plant Projects*. CEC web site. http://www.energy.ca.gov/sitingcases/alphabetical.html

California Energy Commission (CEC) and California Department of Fish and Game. 2007. *California Guidelines for Reducing Impacts to Birds and Bats 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. https:// www.energy.ca.gov/2007publications/CEC-700-2007-008/CEC-700-2007-008-CMF.pdf

Carleton, Scott A., Carlos Martinez Del Rio, and Timothy J. Robinson. 2015. "Feather Isotope Analysis Reveals Differential Patterns of Habitat and Resource Use in Populations of White-Winged Doves." *Journal of Wildlife Management* 79:948–956.

Caswell, Hal. 2001. *Matrix Population Models: Construction, Analysis and Interpretation*, 2nd edition. Sunderland, MA: Sinauer Associates Inc.

Clark, Robert G., Keith A. Hobson, and Leonard I. Wassenaar. 2009. "Corrigendum — Geographic Variation in the Isotopic (δD, δ^{13}C, δ^{15}N, δ^{34}S) Composition of Feathers and Claws from Lesser Scaup and Northern Pintail: Implications for Studies of Migratory Connectivity." *Canadian Journal of Zoology* 87:553–554.

Coulson, Tim, Daniel R. MacNulty, Daniel R. Stahler, Bridgett vonHoldt, Robert K. Wayne, and Douglas W. Smith. 2011. "Modeling Effects of Environmental Change on Wolf Population Dynamics, Trait Evolution, and Life History." *Science* 334:1275–1278.

Coulton, Daniel W., Robert G. Clark, Keith A. Hobson, Leonard I. Wassenaar, and Craig E. Hebert. 2009. "Temporal Sources of Deuterium (δD) Variability in Waterfowl Feathers Across a Prairie-to-Boreal Gradient." *The Condor* 111:255–265.

Courtiol, Alexandre, François Rousset, Marie-Sophie Rohwäder, David X. Soto, Linn S. Lehnert, Christian C. Voigt, Keith A. Hobson, Leonard I. Wassenaar, and Stephanie Kramer-Schadt. 2019. "Isoscape Computation and Inference of Spatial Origins with Mixed Models Using the R Package IsoriX." In *Tracking Animal*

Migration with Stable Isotopes, 2nd edition, eds. Keith A. Hobson and Leonard I. Wassenaar, 207–236. London: Academic Press.

Cryan, Paul M. 2003. "Seasonal Distribution of Migratory Tree Bats (*Lasiurus* and *Lasionycteris*) in North America." *Journal of Mammalogy* 84:579–593.

Cryan, Paul M., Michael A. Bogan, Robert O. Rye, Gary P. Landis, and Cynthia L. Kester. 2004. "Stable Hydrogen Isotope Analysis of Bat Hair as Evidence for Seasonal Molt and Long-Distance Migration." *Journal of Mammalogy* 85:995–1001.

Cryan, Paul M., Craig A. Stricker, and Michael B. Wunder. 2014. "Continental-Scale, Seasonal Movements of a Heterothermic Migratory Tree Bat." *Ecological Applications* 24:602–616.

Dansgaard, W. 1964. "Stable Isotopes in Precipitation." *Tellus* 16:436–468.

DeSante, David F., Danielle R. Kaschube, and James F. Saracco. 2015. *Vital Rates of North American Landbirds*. The Institute for Bird Populations. http://www.vitalratesofnorthamericanlandbirds.org

Economist. 2014. "Green Tape: Environmental Regulations May Not Cost as Much as Governments and Businesses Fear." December 30.

Erickson, Wallace P., Melissa M. Wolfe, Kimberly J. Bay, Douglas H. Johnson, and Joelle L. Gehring. 2014. "A Comprehensive Analysis of Small-Passerine Fatalities from Collision with Turbines at Wind Energy Facilities." *PLoS ONE* 9:e107491.

Fernandez-Juricic, Esteban N., Patrice Baumhardt, and K.L. Kelly. 2018. *How do Different Bird Species Visually Perceive Solar Panels? Implications for Reducing Avian Mortality in Solar Facilities*. American Ornithology Society 2018 Meeting Abstract Book. Tucson, AZ: American Ornithology Society. http://www.americanornithology.org/sites/default/files/AOS2018_AbstractBooklet_27Mar2018.pdf

Ferrer, Miguel, Manuela de Lucas, Guyonne F.E. Janss, Eva Casado, Antonio R. Muñoz, Marc J. Bechard, and Cecilia P. Calabuig. 2012. "Weak Relationship Between Risk Assessment Studies and Recorded Mortality in Wind Farms." *Journal of Applied Ecology* 49:38–46.

Flockhart, D.T. Tyler, Lincoln P. Brower, M. Isabel Ramirez, Keith A. Hobson, Leonard I. Wassenaar, Sonia Altizer, and D. Ryan Norris. 2017. "Regional Climate on the Breeding Grounds Predicts Variation in the Natal Origin of Monarch Butterflies Overwintering in Mexico over 38 Years." *Global Change Biology* 23:2565–2576.

Franson, J. Christian, Lou Sileo, and Nancy J. Thomas. 1995. "Causes of Eagle Deaths." In *Our Living Resources: A Report to the Nation on the Distribution, Abundance,* *and Health of U.S. Plants, Animals, and Ecosystems*, eds. Edward T. LaRoe, Gaye S. Farris, Catherine E. Puckett, Peter D. Doran, and Michael J. Mac, 68. Washington, DC: U.S. Department of the Interior, National Biological Service.

Fraser, Erin E., Liam P. McGuire, Judith L. Eger, Fred J. Longstaffe, and M. Brock Fenton. 2012. "Evidence of Latitudinal Migration in Tri-Colored Bats, *Perimyotis subflavus*." *PLoS ONE* 7: e31419.

Fraser, Kevin C., Emily A. McKinnon, Antony W. Diamond, and Liliana Chavarría. 2011. "The Influence of Microhabitat, Moisture and Diet on Stable-Hydrogen Isotope Variation in a Neotropical Avian Food Web." *Journal of Tropical Ecology* 27:563–572.

Fraser, Erin E., Johnston F. Miller, Fred J. Longstaffe, and M. Brock Fenton. 2015. "Systematic Variation in the Stable Hydrogen Isotope (δ^{2}H) Composition of Fur from Summer Populations of Two Species of Temperate Insectivorous Bats." *Mammalian Biology* 80:278–284.

Frick, W.F., E.F. Baerwald, J.F. Pollock, R.M.R. Barclay, J.A. Szymanski, T.J. Weller, A.L. Russell, S.C. Loeb, R.A. Medellin, and L.P. McGuire. 2017. "Fatalities at Wind Turbines May Threaten Population Viability of a Migratory Bat." *Biological Conservation* 209:172–177.

Gelman, Andrew, John B. Carlin, Hal S. Stern, David B. Dunson, Aki Vehtari, and Donald B. Rubin. 2014. *Bayesian Data Analysis*, 3rd edition. Boca Raton, FL: CRC Press, Taylor & Francis Group.

Guillemain, Matthieu, Steven L. Van Wilgenburg, Pierre Legagneux, and Keith A. Hobson. 2014. "Assessing Geographic Origins of Teal (*Anas crecca*) Through Stable-Hydrogen (δ^{2}H) Isotope Analyses of Feathers and Ring-Recoveries." *Journal of Ornithology* 155:165–172.

Gutiérrez-Expósito, Carlos, Francisco Ramírez, Isabel Afán, Manuela G. Forero, and Keith A. Hobson. 2015. "Toward a Deuterium Feather Isoscape for Sub-Saharan Africa: Progress, Challenges and the Path Ahead." *PLoS ONE* 10:e0135938.

Hein, Cris D., Jeffery Gruver, and Edward B. Arnett. 2013. *Relating Pre-Construction Bat Activity and Post-Construction Bat Fatality to Predict Risk at Wind Energy Facilities: A Synthesis.* Prepared for The National Renewable Energy Laboratory. Austin, TX: Bat Conservation International. https://wild.nrel.gov/sites/default/files/Pre-%20Post-construction%20Synthesis_FINAL%20REPORT.pdf

Hobson, Keith A. 2005. "Stable Isotopes and the Determination of Avian Migratory Connectivity and Seasonal Interactions." *The Auk* 122:1037–1048.

Hobson, Keith A. 2011. "Isotopic Ornithology: A Perspective." *Journal of Ornithology* 152:S49–S66.

Hobson, Keith A., Lisa Atwell, and Leonard I. Wassenaar. 1999. "Influence of Drinking Water and Diet on the Stable-Hydrogen Isotope Ratios of Animal Tissues." *Proceedings of the National Academy of Sciences of the United States of America* 96:8003–8006.

Hobson, Keith A., Gabriel J. Bowen, Leonard I. Wassenaar, Yves Ferrand, and Hervé Lormee. 2004. "Using Stable Hydrogen and Oxygen Isotope Measurements of Feathers to Infer Geographical Origins of Migrating European Birds." *Oecologia* 141:477–488.

Hobson, Keith A., Russell Greenberg, Steven L. Van Wilgenburg, and Claudia Mettke-Hofmann. 2010. "Migratory Connectivity in the Rusty Blackbird: Isotopic Evidence from Feathers of Historical and Contemporary Specimens." *The Condor* 112:778–788.

Hobson, Keith A., and Geoff Koehler. 2015. "On the Use of Stable Oxygen Isotope ($\delta^{18}O$) Measurements for Tracking Avian Movements in North America." *Ecology and Evolution* 5:799–806.

Hobson, Keith A., David X. Soto, Dennis R. Paulson, Leonard I. Wassenaar, and John H. Matthews. 2012a. "A Dragonfly ($\delta^{2}H$) Isoscape for North America: A New Tool for Determining Natal Origins of Migratory Aquatic Emergent Insects." *Methods in Ecology and Evolution* 3:766–772.

Hobson, Keith A., Steve L. Van Wilgenburg, Erica H. Dunn, David J.T. Hussell, Philip D. Taylor, and Douglas M. Collister. 2015. "Predicting Origins of Passerines Migrating Through Canadian Migration Monitoring Stations Using Stable-Hydrogen Isotope Analyses of Feathers: A New Tool for Bird Conservation." *Avian Conservation and Ecology* 10(1):3.

Hobson, Keith A., Steven L. Van Wilgenburg, Jose Luis Guzmán, and Beatriz Arroyo. 2013. "Origins of Juvenile Woodcock (*Scolopax rusticola*) Harvested in Spain Inferred from Stable Hydrogen Isotope ($\delta^{2}H$) Analyses of Feathers." *Journal of Ornithology* 154:1087–1094.

Hobson, Keith A., Steven L. Van Wilgenburg, Keith Larson, and Leonard I. Wassenaar. 2009a. "A Feather Hydrogen Isoscape for Mexico." *Journal of Geochemical Exploration* 102:167–174.

Hobson, Keith A., Steven L. Van Wilgenburg, Leonard I. Wassenaar, and Keith Larson. 2012b. "Linking Hydrogen ($\delta^{2}H$) Isotopes in Feathers and Precipitation: Sources of Variance and Consequences for Assignment to Isoscapes." *PLoS ONE* 7:e35137.

Hobson, Keith A., and Leonard I. Wassenaar. 1997. "Linking Breeding and Wintering Grounds of Neotropical Migrant Songbirds Using Stable Hydrogen Isotopic Analysis of Feathers." *Oecologia* 109:142–148.

Hobson, Keith A., and Leonard I. Wassenaar, eds. 2008. *Tracking Animal Migration with Stable Isotopes*. London: Academic Press.

Hobson, Keith A., Leonard I. Wassenaar, and Orley R. Taylor. 1999. "Stable Isotopes (δD and δ^{13}C) are Geographic Indicators of Natal Origins of Monarch Butterflies in Eastern North America." *Oecologia* 120:397–404.

Hobson, Keith A., Michael B. Wunder, Steven L. Van Wilgenburg, Robert G. Clark, and Leonard I. Wassenaar. 2009b. "A Method for Investigating Population Declines of Migratory Birds Using Stable Isotopes: Origins of Harvested Lesser Scaup in North America." *PLoS ONE* 4:e7915.

Holberton, Rebecca L., Steven L. Van Wilgenburg, Adrienne J. Leppold, and Keith A. Hobson. 2015. "Isotopic (δ^2H_f) Evidence of "Loop Migration" and Use of the Gulf of Maine Flyway by Both Western and Eastern Breeding Populations of Blackpoll Warblers." *Journal of Field Ornithology* 86:213–228.

Hoover, S. 2002. *The Response of Red-Tailed Hawks and Golden Eagles to Topographical Features, Weather, and Abundance of a Dominant Prey Species at the Altamont Pass Wind Resource Area, California: April 1999-December 2000.* Subcontractor Report. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy02osti/30868.pdf

Howell, Steve N.G., Chris Corben, Peter Pyle, and Danny I. Rogers. 2003. "The First Basic Problem: A Review of Molt and Plumage Homologies." *The Condor* 105:635–653.

Hughes, Janice M. 2011. "Greater Roadrunner (*Geococcyx californianus*), version 2.0." In *The Birds of North America*, ed. A.F. Poole. Ithaca, NY: Cornell Lab of Ornithology. https:// doi.org/10.2173/bna.244

Hunt, Grainger. 2002. *Golden Eagles in a Perilous Landscape: Predicting the Effects of Mitigation for Wind Turbine Blade-Strike Mortality*. Consultant Report. Prepared for California Energy Commission, PIER–Environmental Area. https://tethys.pnnl.gov/sites/default/files/publications/Hunt-2002.pdf

Huso, Manuela M.P. 2011. "An Estimator of Wildlife Fatality from Observed Carcasses." *Environmetrics* 22:318–329.

Huso, Manuela, Dan Dalthorp, T.J. Miller, and Dawn Bruns. 2016. "Wind Energy Development: Methods to Assess Bird and Bat Fatality Rates Post-Construction." *Human–Wildlife Interactions* 10:62–70.

Huso, Manuela, Thomas Dietsch, and Chris Nicolai. 2016. *Mortality Monitoring Design for Utility-Scale Solar Power Facilities*. Open-File Report 2016–1087. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey. http://dx.doi.org/10.3133/ofr20161087

IAEA/WMO. 2011. *Global Network of Isotopes in Precipitation*. The GNIP Database. http://www-naweb.iaea.org/napc/ih/IHS_resources_gnip.html

ICF International. 2016. *Altamont Pass Wind Resource Area Bird Fatality Study, Monitoring Years 2005–2013*. Prepared for Alameda County Community Development Agency. Revised from December 2015.

Jardine, Timothy D., and Richard A. Cunjak. 2005. "Analytical Error in Stable Isotope Ecology." *Oecologia* 144:528–533.

Jenkins, A.R., C.S. van Rooyen, J.J. Smallie, J.A. Harrison, M. Diamond, H.A. Smit-Robinson, and S. Ralston. 2015. *Birds and Wind Energy Best-Practice Guidelines: Best-Practice Guidelines for Assessing and Monitoring the Impact of Wind-Energy Facilities on Birds in Southern Africa*, 3rd edition. BirdLife South Africa and Endangered Wildlife Trust. https:// www. birdlife. org.za/documents/avian-wind-farm-sensitivity-map/804-birds-and-wind-bestpractice-guidelines-2015-final

Johnston, Naira N., James E. Bradley, and Ken A. Otter. 2014. "Increased Flight Altitudes Among Migrating Golden Eagles Suggest Turbine Avoidance at a Rocky Mountain Wind Installation." *PLoS ONE* 9:e93030.

Kagan, Rebecca A., Tabitha C. Viner, Pepper W. Trail, and Edgard O. Espinoza. 2014. *Avian Mortality at Solar Energy Facilities in Southern California: A Preliminary Analysis*. National Fish and Wildlife Forensics Laboratory. https://alternativeenergy. procon.org/sourcefiles/avian-mortality-solar-energy-ivanpah-apr-2014.pdf

Katzner, Todd, Victoria Bennett, Tricia Miller, Adam Duerr, Melissa Braham, and Amanda Hale. 2016. "Wind Energy Development: Methods for Assessing Risks to Birds and Bats Pre-Construction." *Human–Wildlife Interactions* 10:42–52.

Katzner, Todd E., Evgeny A. Bragin, and E.J. Milner-Gulland. 2006. "Modelling Populations of Long-Lived Birds of Prey for Conservation: A Study of Imperial Eagles (*Aquila heliaca*) in Kazakhstan." *Biological Conservation* 132:322–335.

Katzner, T., J.A. Johnson, D.M. Evans, T.W.J. Garner, M.E. Gompper, R. Altwegg, T.A. Branch, I.J. Gordon, and N. Pettorelli. 2013. "Challenges and Opportunities for Animal Conservation from Renewable Energy Development." *Animal Conservation* 16:367–369.

Katzner, Todd E., David M. Nelson, Melissa A. Braham, Jacqueline M. Doyle, Nadia B. Fernandez, Adam E. Duerr, Peter H. Bloom, Matthew C. Fitzpatrick, Tricia A. Miller, Renee C.E. Culver, Loan Braswell, and J. Andrew DeWoody. 2017. "Golden Eagle Fatalities and the Continental-Scale Consequences of Local Wind-Energy Generation." *Conservation Biology* 31:406–415.

Kellner, Ken. 2018. *jagsUI: A Wrapper Around 'rjags' to Streamline 'JAGS' Analyses*. R package version 1.5.0. https://CRAN.R-project.org/package=jagsUI

Kéry, Marc, J. Andrew Royle, and Hans Schmid. 2005. "Modeling Avian Abundance from Replicated Counts Using Binomial Mixture Models." *Ecological Applications* 15:1450–1461.

Knick, Steven T., Matthias Leu, John T. Rotenberry, Steven E. Hanser, and Kurt A. Fesenmyer. 2014. "Diffuse Migratory Connectivity in Two Species of Shrubland Birds: Evidence from Stable Isotopes." *Oecologia* 174:595–608.

Kruschke, John K. 2015. *Doing Bayesian Data Analysis: A Tutorial with R, JAGS, and Stan*, 2nd edition. London: Academic Press.

Loss, Scott R., Tom Will, and Peter P. Marra. 2012. "Direct Human-Caused Mortality of Birds: Improving Quantification of Magnitude and Assessment of Population Impact." *Frontiers in Ecology and the Environment* 10:357–364.

Loss, Scott R., Tom Will, and Peter P. Marra. 2013. "Estimates of Bird Collision Mortality at Wind Facilities in the Contiguous United States." *Biological Conservation* 168:201–209.

Lott, Casey A., and Jeff P. Smith. 2006. "A Geographic-Information-System Approach to Estimating the Origin of Migratory Raptors in North America Using Stable Hydrogen Isotope Ratios in Feathers." *The Auk* 123:822–835.

MacArthur, Robert H., and Edward O. Wilson. 1967. *The Theory of Island Biogeography*. Princeton, NJ: Princeton University Press.

Marques, Ana Teresa, Helena Batalha, Sandra Rodrigues, Hugo Costa, Maria João Ramos Pereira, Carlos Fonseca, Miguel Mascarenhas, and Joana Bernardino. 2014. "Understanding Bird Collisions at Wind Farms: An Updated Review on the Causes and Possible Mitigation Strategies." *Biological Conservation* 179:40–52.

Marra, Peter P., Emily B. Cohen, Scott R. Loss, Jordan E. Rutter, and Christopher M. Tonra. 2015. "A Call for Full Annual Cycle Research in Animal Ecology." *Biology Letters* 11:20150552.

Martin, Thomas E., and Geoffrey R. Geupel. 1993. "Nest-Monitoring Plots: Methods for Locating Nests and Monitoring Success." *Journal of Field Ornithology* 64:507–519.

Martin, Tara G., Iadine Chadès, Peter Arcese, Peter P. Marra, Hugh P. Possingham, and D. Ryan Norris. 2007. "Optimal Conservation of Migratory Species." *PLoS ONE* 2:e751.

May, R., O. Reitan, K. Bevanger, S.-H. Lorentsen, and T. Nygård. 2015. "Mitigating Wind-Turbine Induced Avian Mortality: Sensory, Aerodynamic and Cognitive Constraints and Options." *Renewable and Sustainable Energy Reviews* 42:170–181.

McKenney, Bruce A., and Joseph M. Kiesecker. 2010. "Policy Development for Biodiversity Offsets: A Review of Offset Frameworks." *Environmental Management* 45:165–176.

Meyer, David, Achim Zeileis, and Kurt Hornik. 2016. *vcd: Visualizing Categorical Data*. R package version 1.4-3.

Miller, Nathan G., Leonard I. Wassenaar, Keith A. Hobson, and D. Ryan Norris. 2012. "Migratory Connectivity of the Monarch Butterfly (*Danaus plexippus*): Patterns of Spring Re-Colonization in Eastern North America." *PLoS ONE* 7:e31891.

Millsap, Brian A., Emily R. Bjerre, Mark C. Otto, Guthrie S. Zimmerman, and Nathan L. Zimpfer. 2016. *Bald and Golden Eagles: Population Demographics and Estimation of Sustainable Take in the United States, 2016 Update*. Washington, DC: U.S. Fish and Wildlife Service, Division of Migratory Bird Management. https://www.fws.gov/migratorybirds/pdf/management/EagleRuleRevisions-StatusReport.pdf

Moran, Jonathan A., Leonard I. Wassenaar, J. Cam Finlay, Cathie Hutcheson, Leigh Ann Isaac, and Susan M. Wethington. 2013. "An Exploration of Migratory Connectivity of the Rufous Hummingbird (*Selasphorus rufus*), Using Feather Deuterium." *Journal of Ornithology* 154:423–430.

National Audubon Society. 2010. *The Christmas Bird Count Historical Results*. http:// www. christmasbirdcount.org

National Renewable Energy Laboratory. 2017. *Wind-Wildlife Impacts Publications Database*. https:// www.nrel.gov/wind/publications.html

Nelson, David M., Melissa Braham, Tricia A. Miller, Adam E. Duerr, Jeff Cooper, Michael Lanzone, Jérôme Lemaître, and Todd Katzner. 2015. "Stable Hydrogen Isotopes Identify Leapfrog Migration, Degree of Connectivity, and Summer Distribution of Golden Eagles in Eastern North America." *The Condor* 117:414–429.

Newsome, Seth D., Carlos Martinez del Rio, Stuart Bearhop, and Donald L. Phillips. 2007. "A Niche for Isotopic Ecology." *Frontiers in Ecology and the Environment* 5:429–436.

Newsome, Seth D., Justin D. Yeakel, Patrick V. Wheatley, and M. Tim Tinker. 2012. "Tools for Quantifying Isotopic Niche Space and Dietary Variation at the Individual and Population Level." *Journal of Mammalogy* 93:329–341.

Nichols, James D. 1996. "Sources of Variation in Migratory Movements of Animal Populations: Statistical Inference and a Selective Review of Empirical Results for Birds." In *Population Dynamics in Ecological Space and Time*, eds. Olin E. Rhodes, Jr., Ronald K. Chesser, and Michael H. Smith, 147–197. Chicago: University of Chicago Press.

Nordell, Cameron J., Samuel Haché, Erin M. Bayne, Péter Sólymos, Kenneth R. Foster, Christine M. Godwin, Richard Krikun, Peter Pyle, and Keith A. Hobson. 2016. "Within-Site Variation in Feather Stable Hydrogen Isotope (δ^2H_f) Values of Boreal Songbirds: Implications for Assignment to Molt Origin." *PLoS ONE* 11:e0163957.

Northrup, Joseph M., and George Wittemyer. 2013. "Characterising the Impacts of Emerging Energy Development on Wildlife, with an Eye Towards Mitigation." *Ecology Letters* 16(1):112–125.

Oberhauser, Karen, Ruscena Wiederholt, Jay E. Diffendorfer, Darius Semmens, Leslie Ries, Wayne E. Thogmartin, Laura Lopez-Hoffman, and Brice Semmens. 2017. "A Trans-National Monarch Butterfly Population Model and Implications for Regional Conservation Priorities." *Ecological Entomology* 42:51–60.

Pacific Northwest National Laboratory. 2017. Tethys Wind Energy Knowledge Base. https:// tethys.pnnl.gov/knowledge-base-wind-energy

Paula, João, Miguel Costa Leal, Maria João Silva, Ramiro Mascarenhas, Hugo Costa, and Miguel Mascarenhas. 2011. "Dogs as a Tool to Improve Bird-Strike Mortality Estimates at Wind Farms." *Journal for Nature Conservation* 19:202–208.

Pekarsky, Sasha, Alon Angert, Barbara Haese, Martin Werner, Keith A. Hobson, and Ran Nathan. 2015. "Enriching the Isotopic Toolbox for Migratory Connectivity Analysis: A New Approach for Migratory Species Breeding in Remote or Unexplored Areas." *Diversity and Distributions* 21:416–427.

Pennsylvania Game Commission. 2013. *Wind Energy Voluntary Cooperation Agreement, Amendment I.* https://www.pgc.pa.gov/InformationResources/AgencyBusinessCenter/WindEnergy/Documents/Amended%20Cooperative%20Agreement%20and%20Exhibits%20-%202013.pdf

Pillar, Andrew G., Peter P. Marra, Nancy J. Flood, and Matthew W. Reudink. 2016. "Moult Migration in Bullock's Orioles (*Icterus bullockii*) Confirmed by Geolocators and Stable Isotope Analysis." *Journal of Ornithology* 157:265–275.

Plummer, Martyn. 2013. *JAGS: Just Another Gibbs Sampler*, version 3.4.0. http://sourceforge.net/projects/mcmc-jags/files

Popa-Lisseanu, Ana G., Karin Sörgel, Anja Luckner, Leonard I. Wassenaar, Carlos Ibáñez, Stephanie Kramer-Schadt, Mateusz Ciechanowski, Tamás Görföl, Ivo Niermann, Grégory Beuneux, Robert W. Mysłajek, Javier Juste, Jocelyn Fonderflick, Detlev H. Kelm, and Christian C. Voigt. 2012. "A Triple-Isotope Approach to Predict the Breeding Origins of European Bats." *PLoS ONE* 7:e30388.

Powell, L.A., and K.A. Hobson. 2006. "Enriched Feather Hydrogen Isotope Values for Wood Thrushes Sampled in Georgia, USA, During the Breeding Season: Implications for Quantifying Dispersal." *Canadian Journal of Zoology* 84:1331–1338.

Procházka, Petr, Steven L. Van Wilgenburg, Júlio M. Neto, Reuven Yosef, and Keith A. Hobson. 2013. "Using Stable Hydrogen Isotopes (δ^2H) and Ring Recoveries to Trace Natal Origins in a Eurasian Passerine with a Migratory Divide." *Journal of Avian Biology* 44:541–550.

Pylant, Cortney L., David M. Nelson, Matthew C. Fitzpatrick, J. Edward Gates, and Stephen R. Keller. 2016. "Geographic Origins and Population Genetics of Bats Killed at Wind-Energy Facilities." *Ecological Applications* 26:1381–1395.

Pyle, Peter. 1997. *Identification Guide to North American Birds, Part I: Columbidae to Ploceidae.* Bolinas, CA: Slate Creek Press.

Pyle, Peter. 2008. *Identification Guide to North American Birds, Part II: Anatidae to Alcidae*. Point Reyes Station, CA: Slate Creek Press.

Quay, W.B. 1970. "Integument and Derivatives." In *Biology of Bats, Volume II*, ed. William A. Wimsatt, 1–57. New York: Academic Press.

R Core Team. 2016. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org

R Core Team. 2017. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org

Ralph, C. John, John R. Sauer, and Sam Droege. 1995. *Monitoring Bird Populations by Point Counts*. General Technical Report PSW-GTR-149. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Reyes, Gabriel A., Meredith J. Rodriguez, Kenneth T. Lindke, Katherine L. Ayres, Murrelet D. Halterman, Brian B. Boroski, and Dave S. Johnston. 2016. "Searcher Efficiency and Survey Coverage Affect Precision of Fatality Estimates." *Journal of Wildlife Management* 80:1488–1496.

Robillard, Audrey, Gilles Gauthier, Jean-François Therrien, Guy Fitzgerald, Jennifer F. Provencher, and Joël Bêty. 2017. "Variability in Stable Isotopes of Snowy Owl Feathers and Contribution of Marine Resources to Their Winter Diet." *Journal of Avian Biology* 48:759–769.

Royle, J. Andrew. 2004. "*N*-Mixture Models for Estimating Population Size from Spatially Replicated Counts." *Biometrics* 60:108–115.

Royle, J. Andrew, and Robert M. Dorazio. 2008. *Hierarchical Modeling and Inference in Ecology: The Analysis of Data from Populations, Metapopulations, and Communities*. London: Academic Press.

Ruegg, Kristen C., Eric C. Anderson, Ryan J. Harrigan, Kristina L. Paxton, Jeffrey F. Kelly, Frank Moore, and Thomas B. Smith. 2017. "Genetic Assignment with Isotopes and Habitat Suitability (GAIAH), a Migratory Bird Case Study." *Methods in Ecology and Evolution* 8:1241–1252.

Rundel, Colin W., Michael B. Wunder, Allison H. Alvarado, Kristen C. Ruegg, Ryan Harrigan, Andrew Schuh, Jeffrey F. Kelly, Rodney B. Siegel, David F. DeSante, Thomas B. Smith, and John Novembre. 2013. "Novel Statistical Methods for Integrating Genetic and Stable Isotope Data to Infer Individual-Level Migratory Connectivity." *Molecular Ecology* 22:4163–4176.

Runge, Claire A., Tara G. Martin, Hugh P. Possingham, Stephen G. Willis, and Richard A. Fuller. 2014. "Conserving Mobile Species." *Frontiers in Ecology and the Environment* 12:395–402.

Rushing, Clark S., Jeffrey A. Hostetler, T. Scott Sillett, Peter P. Marra, James A. Rotenberg, and Thomas B. Ryder. 2017. "Spatial and Temporal Drivers of Avian Population Dynamics Across the Annual Cycle." *Ecology* 98:2837–2850.

Rushing, Clark S., Peter P. Marra, and Colin E. Studds. 2017. "Incorporating Breeding Abundance into Spatial Assignments on Continuous Surfaces." *Ecology and Evolution* 7:3847–3855.

Sæther, Bernt-Erik, and Øyvind Bakke. 2000. "Avian Life History Variation and Contribution of Demographic Traits to the Population Growth Rate." *Ecology* 81:642–653.

Sauer, J.R., D.K. Niven, J.E. Hines, D.J. Ziolkowski, Jr., K.L. Pardieck, J.E. Fallon, and W.A. Link. 2017. *The North American Breeding Bird Survey, Results and Analysis 1966 – 2015*, version 2.07.2017. Laurel, MD: U.S. Geological Survey Patuxent Wildlife Research Center. https://www.mbr-pwrc.usgs.gov/bbs

Sauer, John R., and William A. Link. 2011. "Analysis of the North American Breeding Bird Survey Using Hierarchical Models." *The Auk* 128:87–98.

Schaub, Michael, and Fitsum Abadi. 2011. "Integrated Population Models: A Novel Analysis Framework for Deeper Insights into Population Dynamics." *Journal of Ornithology* 152:S227–S237.

Schumaker, Nathan H., Allen Brookes, Jeffrey R. Dunk, Brian Woodbridge, Julie A. Heinrichs, Joshua J. Lawler, Carlos Carroll, and David LaPlante. 2014. "Mapping Sources, Sinks, and Connectivity Using a Simulation Model of Northern Spotted Owls." *Landscape Ecology* 29:579–592.

Seamans, Mark E. 2018. *Mourning Dove Population Status, 2018*. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, Division of Migratory Bird Management. https://www.fws.gov/migratorybirds/pdf/surveys-and-data/Population-status/MourningDove/MourningDovePopulationStatus18.pdf

Seifert, Nina, Martin Haase, Steven L. Van Wilgenburg, Christian C. Voigt, and Angela Schmitz Ornés. 2016. "Complex Migration and Breeding Strategies in an Elusive Bird Species Illuminated by Genetic and Isotopic Markers." *Journal of Avian Biology* 47:275–287.

Shuford, W. David, Nils Warnock, Kathy C. Molina, and Kenneth K. Sturm. 2002. "The Salton Sea as Critical Habitat to Migratory and Resident Waterbirds." *Hydrobiologia* 473:255–274.

Shump, Karl A., and Ann U. Shump. 1982a. "Lasiurus borealis." *Mammalian Species* 183:1–6.

Shump, Karl A., and Ann U. Shump. 1982b. "Lasiurus cinereus." *Mammalian Species* 185:1–5.

Sillett, T. Scott, Richard B. Chandler, J. Andrew Royle, Marc Kéry, and Scott A. Morrison. 2012. "Hierarchical Distance-Sampling Models to Estimate Population Size and Habitat-Specific Abundance of an Island Endemic." *Ecological Applications* 22:1997–2006.

Smallwood, K. Shawn. 2013. "Comparing Bird and Bat Fatality-Rate Estimates Among North American Wind-Energy Projects." *Wildlife Society Bulletin* 37:19–33.

Smallwood, K. Shawn, and Carl Thelander. 2008. "Bird Mortality in the Altamont Pass Wind Resource Area, California." *Journal of Wildlife Management* 72:215–223.

Smith, Adam D., Kara Donohue, and Alfred M. Dufty. 2008. "Intrafeather and Intraindividual Variation in the Stable-Hydrogen Isotope (δD) Content of Raptor Feathers." *The Condor* 110:500–506.

Sollmann, Rahel, Beth Gardner, Kathryn A. Williams, Andrew T. Gilbert, and Richard R. Veit. 2016. "A Hierarchical Distance Sampling Model to Estimate Abundance and Covariate Associations of Species and Communities." *Methods in Ecology and Evolution* 7:529–537.

Stahl, Justyn T., and Madan K. Oli. 2006. "Relative Importance of Avian Life-History Variables to Population Growth Rate." *Ecological Modelling* 198:23–39.

Strickland, Dale, Edward Arnett, Wallace Erickson, Douglas Johnson, Gregory Johnson, Michael Morrison, Jill Shaffer, and William Warren-Hicks. 2011. *Comprehensive Guide to Studying Wind Energy/Wildlife Interactions.* Prepared for the National Wind Coordinating Collaborative, Washington, DC. https://tethys.pnnl.gov/sites/default/files/publications/Comprehensive-Guide-to-Studying-Wind-Energy-Wildlife-Interactions.pdf

Sullivan, Alexis R., Joseph K. Bump, Laura A. Kruger, and Rolf O. Peterson. 2012. "Bat-Cave Catchment Areas: Using Stable Isotopes (δD) to Determine the Probable Origins of Hibernating Bats." *Ecological Applications* 22:1428–1434.

Sullivan, Brian L, Christopher L. Wood, Marshall J. Iliff, Rick E. Bonney, Daniel Fink, and Steve Kelling. 2009. "eBird: A Citizen-Based Bird Observation Network in the Biological Sciences." *Biological Conservation* 142:2282–2292.

Terzer, S., L.I. Wassenaar, L.J. Araguás-Araguás, and P.K. Aggarwal. 2013. "Global Isoscapes for $\delta^{18}O$ and $\delta^{2}H$ in Precipitation: Improved Prediction Using Regionalized Climatic Regression Models." *Hydrology and Earth System Sciences* 17:4713–4728.

Thompson, Maureen, Julie A. Beston, Matthew Etterson, Jay E. Diffendorfer, and Scott R. Loss. 2017. "Factors Associated with Bat Mortality at Wind Energy Facilities in the United States." *Biological Conservation* 215:241–245.

Trueman, Clive N., Kirsteen M. MacKenzie, and Katie St John Glew. 2017. "Stable Isotope-Based Location in a Shelf Sea Setting: Accuracy and Precision are Comparable to Light-Based Location Methods." *Methods in Ecology and Evolution* 8:232–240.

U.S. Fish and Wildlife Service. 2012. *U.S. Fish and Wildlife Service Land–Based Wind Energy Guidelines*. https://www.fws.gov/ecological-services/es-library/pdfs/WEG_final.pdf

U.S. Fish and Wildlife Service. 2013. *Eagle Conservation Plan Guidance: Module 1 – Land-Based Wind Energy*, version 2. https://www.fws.gov/migratorybirds/pdf/management/eagleconservationplanguidance.pdf

Unitt, Phil. 2004. *The Birds of San Diego County: Greater Roadrunner*. San Diego, CA: Sunbelt Publications. http://sdplantatlas.org/BirdAtlas/BirdPages.aspx

Van Wilgenburg, Steven L., and Keith A. Hobson. 2011. "Combining Stable-Isotope (δD) and Band Recovery Data to Improve Probabilistic Assignment of Migratory Birds to Origin." *Ecological Applications* 21:1340–1351.

Van Wilgenburg, Steven L., Keith A. Hobson, Katherine R. Brewster, and Jeffrey M. Welker. 2012. "Assessing Dispersal in Threatened Migratory Birds Using Stable Hydrogen Isotope (δD) Analysis of Feathers." *Endangered Species Research* 16:17–29.

Vander Zanden, Hannah B., David M. Nelson, Michael B. Wunder, Tara J. Conkling, and Todd Katzner. 2018. "Application of Isoscapes to Determine Geographic Origin of Terrestrial Wildlife for Conservation and Management." *Biological Conservation* 228:268–280.

Vander Zanden, Hannah B., Joseph B. Pfaller, Kimberly J. Reich, Mariela Pajuelo, Alan B. Bolten, Kristina L. Williams, Michael G. Frick, Brian M. Shamblin, Campbell J. Nairn, and Karen A. Bjorndal. 2014b. "Foraging Areas Differentially Affect Reproductive Output and Interpretation of Trends in Abundance of Loggerhead Turtles." *Marine Biology* 161:585–598.

Vander Zanden, Hannah B., David X. Soto, Gabriel J. Bowen, and Keith A. Hobson. 2016. "Expanding the Isotopic Toolbox: Applications of Hydrogen and Oxygen Stable Isotope Ratios to Food Web Studies." *Frontiers in Ecology and Evolution* 4:20.

Vander Zanden, Hannah B., Anton D. Tucker, Kristen M. Hart, Margaret M. Lamont, Ikuko Fujisaki, David S. Addison, Katherine L. Mansfield, Katrina F. Phillips, Michael B. Wunder, Gabriel J. Bowen, Mariela Pajuelo, Alan B. Bolten, and Karen A. Bjorndal. 2015. "Determining Origin in a Migratory Marine Vertebrate: A Novel Method to Integrate Stable Isotopes and Satellite Tracking." *Ecological Applications* 25:320–335.

Vander Zanden, Hannah B., Michael B. Wunder, Keith A. Hobson, Steven L. Van Wilgenburg, Leonard I. Wassenaar, Jeffrey M. Welker, and Gabriel J. Bowen. 2014a. "Contrasting Assignment of Migratory Organisms to Geographic Origins Using Long-Term Versus Year-Specific Precipitation Isotope Maps." *Methods in Ecology and Evolution* 5:891–900.

Vander Zanden, M. Jake, Murray K. Clayton, Eric K. Moody, Christopher T. Solomon, and Brian C. Weidel. 2015. "Stable Isotope Turnover and Half-Life in Animal Tissues: A Literature Synthesis." *PLoS ONE* 10:e0116182.

Ventus Environmental Solutions. 2016. *Final Report, 2012–2015 Avian and Bat Monitoring Project, Vasco Winds, LLC*. Prepared for NextEra Energy Resources.

Walston Jr., Leroy J., Katherine E. Rollins, Kirk E. LaGory, Karen P. Smith, and Stephanie A. Meyers. 2016. "A Preliminary Assessment of Avian Mortality at Utility-Scale Solar Energy Facilities in the United States." *Renewable Energy* 92:405–414.

Warne, Robin W., Glenn A. Proudfoot, and Erica J. Crespi. 2015. "Biomarkers of Animal Health: Integrating Nutritional Ecology, Endocrine Ecophysiology, Ecoimmunology, and Geospatial Ecology." *Ecology and Evolution* 5:557–566.

Wassenaar, Leonard I. 2008. "An Introduction to Light Stable Isotopes for Use in Terrestrial Animal Migration Studies." In *Tracking Animal Migration with Stable Isotopes*, eds. Keith A. Hobson and Leonard I. Wassenaar, 21–44. London: Academic Press.

Wassenaar, Leonard I., and Keith A. Hobson. 2006. "Stable-Hydrogen Isotope Heterogeneity in Keratinous Materials: Mass Spectrometry and Migratory Wildlife Tissue Subsampling Strategies." *Rapid Communications in Mass Spectrometry* 20:2505–2510.

Waterisotopes.org. 2017. WaterIsotopes.org web site. http://wateriso.utah.edu/waterisotopes/index.html

Webster, Michael S., Peter P. Marra, Susan M. Haig, Staffan Bensch, and Richard T. Holmes. 2002. "Links Between Worlds: Unraveling Migratory Connectivity." *Trends in Ecology & Evolution* 17:76–83.

Western EcoSystems Technology, Inc. 2009. *Avian Baseline Studies for the Alta-Oak Creek Mojave Wind-Energy Project, Kern County, California, Summary of Results, February 4 – July 11, 2009*. Prepared for CH2M HILL. https://www.kerncounty.com/planning/pdfs/eirs/altaoakcreek/AltaOakCreek_C-4.pdf

Western EcoSystems Technology, Inc. and Bat Conservation International. 2014. *A Bibliography of Bat Fatality, Activity, and Interactions with Wind Turbines*. https://tethys.pnnl.gov/sites/default/files/publications/Arnett_and_Hein_2004.pdf

White, Gary C. 2005. "Correcting Wildlife Counts Using Detection Probabilities." *Wildlife Research* 32:211–216.

Wittenberg, Sara Ress, Sarah E. Lehnen, and Kimberly Smith. 2013. "Use of Stable Isotopes of Hydrogen to Predict Natal Origins of Juvenile Merlins and Northern Harriers Migrating Through the Florida Keys." *The Condor* 115:451–455.

Wolfe, David W., K. Brian Hays, Shannon L. Farrell, and Susan Baggett. 2012. "Regional Credit Market for Species Conservation: Developing the Fort Hood Recovery Credit System." *Wildlife Society Bulletin* 36:423–431.

Wunder, Michael B. 2012. "Determining Geographic Patterns of Migration and Dispersal Using Stable Isotopes in Keratins." *Journal of Mammalogy* 93:360–367.

Wunder, Michael B., Keith A. Hobson, Jeff Kelly, Peter P. Marra, Leonard I. Wassenaar, Craig A. Stricker, and Richard R. Doucett. 2009. "Does a Lack of Design and Repeatability Compromise Scientific Criticism? A Response to Smith et al." *The Auk* 126:922–926.

Wunder, Michael B., Joseph R. Jehl Jr, and Craig A. Stricker. 2012. "The Early Bird Gets the Shrimp: Confronting Assumptions of Isotopic Equilibrium and Homogeneity in a Wild Bird Population." *Journal of Animal Ecology* 81:1223–1232.

Wunder, Michael B., and D. Ryan Norris. 2008. "Improved Estimates of Certainty in Stable-Isotope-Based Methods for Tracking Migratory Animals." *Ecological Applications* 18:549–559.

Yin, Hongfu, Weihong He, and Shucheng Xie. 2011. "How Severe is the Modern Biotic Crisis?—A Comparison of Global Change and Biotic Crisis Between Permian-Triassic Transition and Modern Times." *Frontiers of Earth Science* 5:1–13.

APPENDIX A: Selection of Focal Species

Background

The authors were funded to evaluate effects to wildlife of fatalities at renewable energy facilities. They proposed to do this by building demographic models for species affected by fatalities at renewable energy facilities. These models would also be informed by stable isotope analysis of local and nonlocal origins of birds and bats killed at facilities – data that can be used to parameterize some animal movement rates (especially immigration). Although the spatial extent of the project was not explicitly defined, it was clearly important to focus especially on species relevant to California. However, since demographic models cannot be built for all species, the authors needed some mechanism to filter species and arrive at a species list that was both relevant to managers and manageable to scientists.

The approach to solving this problem was to convene a panel of outside experts (listed below) and solicit their opinions on how to balance conservation relevance, threats from renewable energy, and availability of information on species. For example, there are species of great conservation value but for whom there are little available demographic or movement data. Likewise, there are species that are widely abundant and not of conservation concern and also very well-studied and easy to model. The authors wished to solicit expert opinion on how to choose among these types of species and also, specifically, which species to model. They felt that a reasonable target would be 10—30 species, the exact number depending on the modeling approach taken (bearing in mind that a one-size-fits-all modeling approach would allow the incorporation of more species).

On March 13—14, 2017, the research team held a 2-day workshop in Davis, California. In the morning of the first day of the meeting, the authors presented the experts with a summary of the goals of the project (Katzner) and the work done to date and ideas for next steps (Conkling, Vander Zanden). These presentations were highly interactive and provided both a good summary of the work done and extremely helpful feedback from experts. Meetings after lunch began with a summary of potential types of demographic models (Diffendorfer). Subsequently, the team began an extended discussion on what types of rules should be applied to make decisions about including or excluding species in modeling efforts. Finally, once the team had a framework for rules, they began to apply them to several species.

On the second day of the meeting, the authors convened only with the applicant team (and one outside expert, Rodriguez, from California Department of Fish and Wildlife). They reviewed additional species to finalize the species list and developed a framework for demographic modeling of these species. They also discussed how best to break up the project results into publishable units.

Below is a summary of the decision-making framework for inclusion or exclusion of species and a description of the modeling approach.

Decision-Making Framework

The expert panel discussions focused on three different ways to approach the problem of categorizing species. To broadly generalize, these were: (1) to identify different model types and then pick species that fit well into those model types; (2) to group species by guild or type or some other category, so that when building a model for a given species, if the category that species fits into is known, then a manager can use that to infer information about other species they think are in that category; and (3) to model ideal species by guild and then demonstrate the relevance of this approach with a few species-specific examples.

All parties appeared to agree that each of these approaches had merits and, eventually, they incorporated elements of each approach into the decision-making process. They began the decision-making process by identifying categories of information that they could use to differentiate among types of species. These categories were:

- Scale of the species distribution. Possible classes were continental, middle, and local.
- Type of model expected to be built. Classes were complex (demographically or spatially) or general.
- Quality of stable isotope information in this study. Classes were high, medium, low, and none.
- Conservation relevance (as estimated by presence on state lists, federal lists, and so forth). Classes were high, medium, and low.
- Migratory behavior. Classes were nonmigratory, winter in California, summer in California, partially migratory, or present in all seasons.
- Ecological value (this captures both uniqueness in the data set and also things like keystone or indicator species). Classes were high, medium, and low.
- Regulatory interest (this captures the significance to state or federal managers). Classes were high, medium, and low.
- Impact to species by renewable energy facilities. Classes were high, medium, and low, with a separate column for direct and indirect effects.
- The team also made the conscious decision to only focus on native species. Thus, for example, starlings, rock doves, and collared doves were excluded from the potential list.
- Cuteness was considered as a possible inclusion factor. It was decided by executive fiat that there would be plenty of cute species on the final list, no

matter which ones the team chose. In the face of great resistance, the facilitator used his prerogative to steer the discussion away from this topic.

Decision-Making

The team then worked through a number of species lists, trying to select a group of species that allowed them to capture the diversity of different classes in each category. They chose species from four lists, including (1) those that were present in abundance in fatality reports from wind facilities; (2) those abundant in fatality reports from solar facilities; (3) those for which the team had numerous fatality specimens for use in stable isotope analysis; and (4) those that were the focus of ongoing genoscape studies being conducted by Kristen Ruegg, Tom Smith, and others. Because this approach relied heavily on species in fatality reports or found dead, and because the team, therefore, ignored important issues such as detection biases inherent in those reports, they also made sure to consider some other species that may not be present in large numbers in reports but for which there was conservation concern. To broaden the list in this manner, they also included a few other species that appear on state threatened, endangered, and conservation need lists and selected several of these that may be detected rarely or that have unusual demography or biology.

After discussions and winnowing, the team finalized a list of 34 species (see Table 7 and Table 8 for the list of species). Many other species were considered and excluded, but those discussions are not summarized here.

Frameworks for Demographic Modeling

The research team discussed several types of modeling, using those identified on day 1 by Diffendorfer. Discussions focused on the fact that the team wished to incorporate both spatial and temporal variability in models and that there were probably several types of models that would be required to encompass the variation in life history and information available for the 34 species. The team also realized that inclusion of some type of estimates of potential biological removal (*PBR*) would be an important element to include in the models.

After discussion, the team realized that the best approach to modeling would be to use a single framework that would allow for extensive spatial and temporal variability. They settled on using a mega-matrix approach to demographic modeling. In this approach, each species is modeled with a large matrix model (for example, a 10 x 10 matrix). The columns in such a matrix represent combinations of age classes structured by location (for example, adults in breeding location and adults in overwintering location). The rows are either inputs (fecundity or immigration, by age class) or transition probabilities from one age class or location to the next (survival through time, or survival during migration or movement). The simplest model might only have two life stages and no spatial variability. In this scenario, there would be no immigration, reproduction only by adults, and survival probabilities only for two age classes (juvenile and adult). A more complex model might have different fecundity for each age class and could incorporate immigration (by altering fecundity to allow for extra juveniles or by altering survival to allow for extra individuals of other age classes). An even more complex model may have season-specific survival rates (thus, each age class might be represented by two columns, one that describes summer survivorship and fecundity and another for winter survivorship and fecundity).

There are several important reasons why this approach is valuable. First, it streamlines the work required to model such a large group of species, which is important given the time frames of this project. Second, it is inherently flexible and allows the incorporation of all the spatial and temporal variability that may be described by the life histories of the species being considered. Third, it allows flexibility in terms of how much generality or complexity to incorporate, given available information on each species. Finally, matrix models share many of the demographic parameters required to estimate PBR. By using matrix models, the research team was able to calculate PBR for many species as well.

Finally, the team assigned each of the 34 species evaluated into one of five groups based on movement behavior and that corresponded to the type of matrix model expected to be produced. These groups are:

1) **Breeding season only.** These are species that spend only the breeding season in California. The models focused on breeding season events only and, thus, they incorporated both spatial and temporal information. Good examples of these are Neotropical migrants. The species on the list that appear in the breeding season are Mexican free-tailed bats, Swainson’s hawk, Wilson’s warbler, Yellow warbler, willow flycatcher, bank swallow, and lesser nighthawk. The Swainson’s hawk model was unique, as this species is affected by habitat loss, not direct mortality.
2) **Winter season only.** These are species that spend only the winter season in California (although several of the species on this list do breed in California, they are alpine breeders and only encounter existing renewable energy in winter). These models focused on winter season events only and again they incorporated both spatial and temporal information in this manner. Good examples of these are waterbirds that may winter in the Salton Sea or the Sea of Cortez. The species on the list that appear during the winter season are hoary bat, eared grebe, western grebe, yellow-rumped warbler, common loon, ruddy duck, white-crowned sparrow, and American white pelican.
3) **Full-year models – simple**. These are species that are year-round residents in California. The list includes several near-endemics and species of high conservation concern, each with unique demography. In most cases, each of these were modeled with a fairly simple model that did not incorporate much spatial or temporal variability. The five species on this list are white-tailed kite, black rail, greater roadrunner, tri-colored blackbird, and western yellow-billed cuckoo.

4) **Multiseason models – complex.** These are species that are year-round residents in California. They differ from the previous group because their biology and movement are both complex and more thoroughly understood. This is a diverse group of species that includes raptors, gamebirds, warblers, and aerial insectivores. Species on this list include western meadowlark, red-tailed hawk, American kestrel, burrowing owl, barn owl, horned lark, golden eagle, mourning dove, great-horned owl, house finch, tree swallow, and common yellowthroat.
5) **Migrant only.** These are species that are present in California only during migration. These models were more difficult to build and interpret, but they represented an unusual group of species whose biology the team wanted to be sure to include in the analyses. There are two species on this list – rufous hummingbird and red-necked phalarope.

Note that the ultimate modeling approach used in this project differed slightly from that proposed here, although it incorporated many of the elements of this approach.

Reporting

It has been said that if science was not subjected to peer-review and published, then it was never done. In addition to providing a final report to the Energy Commission, the team intended to illustrate the quality and relevance of the science by publishing this work. To do this, they divided the research program into five publishable units. These units described the process and outcomes of the research work the team was contracted to perform. These units also formed the framework for the final report and informed the decision tools provided to the Energy Commission in this final report.

The five publishable components of this research were:

1) A paper describing the application of stable isotope tools to conservation decision-making. This work was important because, although stable isotope tools have been used in ecological science, they are rarely used in conservation science. This effort was led by Vander Zanden with support from Nelson, Katzner, and others (see Chapter 4).
2) A paper describing the applicability of existing consultant monitoring reports and renewable energy facilities for use in comparison of pre- and post-construction and mitigation actions. This work was important because it illustrated that the vast majority of surveys at renewable energy facilities are done in such a way that pre- and post-comparison is nearly impossible. This effort was led by Conkling with support from Yee, Loss, Allison, Katzner, and others (see Chapters 2 and 3).
3) A paper describing the framework for application of matrix population modeling to the problem of estimating effects of anthropogenic influences on species for a broad and diverse group of species that spend different amounts of time within biologically unimportant political boundaries. This work was important because it developed a new framework for application of a tried and true technique (matrix

models) to a complex modern management problem. This effort was led by Conkling, with support from Diffendorfer, Duerr, Loss, Katzner, and others (see Chapter 6).

4) A paper describing the portion of fatalities at renewable energy facilities in California that were nonlocal to the location where they were killed. This work was important because it categorized, for California, the degree to which species killed within the state are entirely local or spend part of their year outside of the state. This work was led by Vander Zanden with support from Nelson, Trish Miller, Braham, Katzner, and others (see Chapter 5).
5) A paper describing the impact, to populations of ~30+ wildlife species, of fatalities at renewable energy facilities in California. This paper will be the final product of this work and will tie together the stable isotope tools and results with the modeling approach to describe how these species are affected by fatalities at renewable energy facilities. The work is important because it will be, to the research team's knowledge, the first time that such detailed and well-informed models will be developed for species at the state scale. This work will be led by Conkling and Katzner, with support from all other applicants on the research team.

Summary

The summary of outcomes of the renewable energy research planning meeting is as follows:

- An expert panel was convened to assist in identification of focal species for a project to understand effects to wildlife of fatalities at renewable energy facilities.
- Experts felt that rather than focusing exclusively on wildlife for whom there were documented large numbers of fatalities, choosing species by type or guild was critical.
- Together with experts, the research team developed a list of 34 species of five types on which to focus.
- These included species killed in large numbers at renewable energy facilities, but also species not noted in large numbers but (a) of high conservation concern, (b) that represented a wide variety of life history types, and (c) truly unusual species that may be affected by renewable energy.
- The research team developed a matrix modeling framework that would allow them to build five types of demographic models, one for each type of the 34 species of interest. These models allowed the team to incorporate information from other parts of this research focused on evaluating reports from renewable energy facilities and on stable isotope analysis of fatalities.

- Finally, publications are essential for science and the research team identified five different publications to be produced by this research. These publications formed the basis for the final report to the Energy Commission funders of this project.

Participants

Research Team:

Taber Allison, American Wind Wildlife Institute

Melissa Braham, West Virginia University

Tara Conkling, U.S. Geological Survey

Jay Diffendorfer, U.S. Geological Survey

Adam Duerr, West Virginia University and Bloom Biological, Inc.

Todd Katzner, U.S. Geological Survey

Scott Loss, Oklahoma State University

Hannah Vander Zanden, U.S. Geological Survey and University of Florida

Julie Yee, U.S. Geological Survey

External Experts:

Peter Bloom, Bloom Biological, Inc.

Amy Fesnock, Bureau of Land Management

Garry George, California Audubon Society

Manuela Huso, U.S. Geological Survey

Magdalena Rodriguez, California Department of Fish and Wildlife

Kristen Ruegg, University of California, Los Angeles

David Stoms, California Energy Commission

Ted Weller, U.S. Forest Service

Lisa Nordstrom, San Diego Zoo

Tom Diestch, U.S. Fish and Wildlife Service

Wayne Spencer, Conservation Biology Institute

Heather Beeler, U.S. Fish and Wildlife Service

Carol Watson, California Energy Commission

APPENDIX B: Abstract from Published Paper "Effect of Heat and Singeing on Stable Hydrogen Isotope Ratios of Bird Feathers and Implications for Their Use in Determining Geographic Origin"

This abstract is from an article published by some of the authors of this report. It is provided here in the format required by the journal in which it was published.

Rationale: Stable hydrogen isotope (δ^2H) ratios of animal tissues are useful for assessing movement and geographic origin of mobile organisms. However, it is uncertain whether heat and singeing affects feather δ^2H values and thus subsequent geographic assignments. This is relevant for birds of conservation interest that are burned and killed at concentrating solar-energy facilities that reflect sunlight to a receiving tower and generate a solar flux field.

Methods: We used a controlled experiment to test the effect of known heat loads (exposure to 200, 250 or 300°C for 1 min) on the morphology and δ^2H values of feathers from two songbird species. Subsequently, we examined the effects of singeing on δ^2H values of feathers from three other songbird species that were found dead in the field at a concentrating solar-energy facility.

Results: Relative to control samples, heating caused visual morphological changes to feathers, including shriveling at 250°C and charring at 300°C. The δ^2H values significantly declined by a mean of 27.8‰ in experimental samples exposed to 300°C. There was no statistically detectable difference between δ^2H values of the singed and unsinged portions of field-collected feathers from the same bird.

Conclusions: Limited singeing that did not dramatically alter the feather morphology did not substantially affect δ^2H values of feathers from these songbirds. However, higher temperatures induced charring and reduced δ^2H values. Therefore, severely charred feathers should be avoided when selecting feathers for δ^2H-based assessment of geographic origin.

Vander Zanden, Hannah B., Abigail Reid, Todd Katzner, and David M. Nelson. 2018. "Effect of Heat and Singeing on Stable Hydrogen Isotope Ratios of Bird Feathers and Implications for Their Use in Determining Geographic Origin." *Rapid Communications in Mass Spectrometry* 32:1859–1866.

APPENDIX C: Details of Modeling Framework and Implementation

Modeling Framework

Since annual indices from BBS data were nonintegers, the authors modeled population counts (*N*s) at time *t* as a Gamma distribution. *Gamma*(α,β) with parameters α and β (shape and rate, respectively) was formulated in terms of mean population size at time *t* ($N_{\text{tot},t}$) and species-specific precision τ_{pop} for population size in the model, where

$$\alpha = N_{\text{tot},t}{}^{2} \times \tau_{\text{pop}} \text{ and } \beta = N_{\text{tot},t} \times \tau_{\text{pop}} \qquad \text{[Equation 1]}$$

The authors estimated precision with:

$$\tau_{\text{pop}} \sim Normal(\mu_{Ns.diff}, \tau_{Ns.diff}) \qquad \text{[Equation 2]}$$

and

$$Ns.diff = (Upper\ 95\%\ BBS\ CrI - Lower\ 95\%\ BBS\ CrI)/4 \qquad \text{[Equation 3]}$$

where *Ns.diff* equaled the difference between the 95 percent CrI for annual indices provided in the BBS dataset (Sauer et al. 2017) divided by 4 to approximate 2 *SD* on either side of the mean.

The simple projection matrix model had a model structure and complexity that varied by species to reflect species-specific differences in the number of annual life stages (juvenile, immature, adult) and first breeding age. As an example, many species in the Order Passeriformes breed in their second year of life (2y) and only require a two-age (juvenile, adult) 2 x 2 matrix model. In contrast, species such as golden eagles that do not reach breeding age until 4+ years require a 5 x 5 population matrix with three age classes (juvenile, immature, and adult). As such, the total number of individuals in a given year ($N_{\text{tot},t}$) included the sum of all adults plus individuals in other year classes where x = first breeding age (for example, if first breeding age ≥1 year old, $N_x = N_1$).

$$N_{\text{tot},t} = N_{\text{ad},t} + \sum_{i=1}^{x} N_{x,t} \qquad \text{[Equation 4]}$$

The authors estimated the number of individuals surviving their first year (N_1) in year *t* with the state-process model defined as:

$$N_{1,t} \sim Gamma([N_{\text{ad},t-1} fec_{t-1} \Phi_{1y,t-1}]^2 \times \tau_{\text{pop}}, [N_{\text{ad},t-1} fec_{t-1} \Phi_{1y,t-1}] \times \tau_{\text{pop}}) \qquad \text{[Equation 5]}$$

with surviving breeding adults from year t–1 ($N_{\text{ad},t-1}$), fecundity (*fec*), and juvenile annual survival ($\Phi_{1\text{y}}$).

The authors estimated the number of individuals in each subsequent prebreeding age class (for example, N_2, N_3, N_4 for golden eagles) by:

$$N_{x,t} \sim Gamma([\mu_{N_{x,t}}{}^{2} \times \sigma^{2}{}_{N_{x,t}}], [\mu_{N_{x,t}} \times \sigma^{2}{}_{N_{x,t}}])$$ [Equation 6]

$$\mu_{N_{x,t}} = N_{x-1,t-1} * \Phi_x$$ [Equation 7]

$$\sigma^{2}{}_{N_{x,t}} = N_{x-1,t-1} * \Phi_x * (1 - \Phi_x)$$ [Equation 8]

where N_x is the estimated number of individuals that are x years old and Φ_x is age-specific survival, with $\Phi_{1y} = \Phi_x$ if there were only two stages of survival in the model (juvenile and adult) versus three stages (for example, $\Phi_{1y} \neq \Phi_{2y}$, $\Phi_{2y} = \Phi_{3y} = \Phi_{4y}$).

The authors estimated the number of breeding individuals (N_{ad}) by calculating the number of adults that survived the previous year ($N_{ad,t-1}$) plus the surviving individuals from the last age class before reaching sexual maturity ($N_{ad-1,t-1}$), which varied by species (for example, N_1 if the species breeds at age 2, N_4 if the species breeds at age 5), where:

$$N_{ad,t} \sim Gamma([\mu_{N_{x,t}}{}^{2} \times \sigma^{2}{}_{N_{x,t}}], [\mu_{N_{x,t}} \times \sigma^{2}{}_{N_{x,t}}])$$ [Equation 9]

$$\mu_{N_{ad,t}} = (N_{ad-1,t-1} + N_{ad,t-1}) * \Phi_{ad}$$ [Equation 10]

$$\sigma^{2}{}_{N_{ad,t}} = (N_{ad-1,t-1} + N_{ad,t-1}) * \Phi_x * (1 - \Phi_x)$$ [Equation 11]

Model Implementation

If mean (μ) and variance (σ^2) estimates for juvenile (ϕ_{1y}), immature (ϕ_{2y}), or adult (ϕ_a) survival were available in the literature, the authors converted these estimates into an informative Beta prior distribution $Beta(\alpha,\beta)$ for survival parameters, where:

$$\alpha = \frac{\mu(\sigma^2 + \mu^2 - \mu)}{\sigma^2} \text{ and } \beta = \frac{(\sigma^2 + \mu^2 - \mu)(\mu - 1)}{\sigma^2}$$ [Equation 12]

(Table 7). Otherwise they used weakly informative $\sim Beta(2,2)$ priors (Kruschke 2015). Similarly, they constructed informative $Gamma(\alpha,\beta)$ priors for fecundity (*fec*) based on mean and variance estimates from the literature, where:

$$\alpha = \left(\frac{\mu}{\sigma}\right)^2 \text{ and } \beta = \frac{\mu}{\sigma^2}$$ [Equation 13]

They used $Gamma(0.01, 0.01)$ when no fecundity information was available (Table 7).

When building a model to estimate λ, there can be multiple combinations of demographic model parameters that can give the same λ value. This problem is termed *nonidentifiability*. Given this problem, the authors used the following system to constrain the models so that they output reasonable demographic parameters. First, the authors truncated ϕ_{1y} and ϕ_{2y} priors $T(0,\phi_a)$, with the assumption that adult survival was always greater than survival for juvenile and immature age classes. They also constrained the *fec* prior by the species-specific maximum number of offspring per individual per year (that is, $T[0, \frac{1}{2} \times \text{maximum clutch size}]$). They then constructed three candidate models for each species with increasing constraints on model priors (μ_{ϕ} and μ_{fec}) such that they could have: (1) no constraints on prior distributions; (2) survival: μ_{ϕ} ± 0.2, fecundity: μ_{fec} ± 50 percent; and (3) survival: μ_{ϕ} ± 0.1, fecundity: μ_{fec} ± 25 percent.

The authors ran the models by sampling from nine independent Markov chains with a burn-in of 50,000, thinning of 1,000, and 200,000 iterations. They used deviance information criteria values to select the best-fit model for subsequent analyses. Finally, they examined traceplots and posterior distributions and assumed model convergence when $\hat{R} < 1.1$ (Gelman et al. 2014). They generated year-specific parameter estimates and calculated the geometric mean and *SD* for each parameter to compare the model results across all years.