# Comprehensive Guide to Studying Wind Energy/Wildlife Interactions

Prepared for the National Wind Coordinating Collaborative
June 2011

National Wind Coordinating Collaborative

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# COMPREHENSIVE GUIDE TO STUDYING WIND ENERGY/WILDLIFE INTERACTIONS


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# PREFACE

This document is a product of the National Wind Coordinating Collaborative (NWCC) Wildlife Workgroup. It is being released as a Resource Document for educational and informational purposes. The document has been reviewed and approved by an NWCC working group with relevant experience; but, by choice of the NWCC, has not been carried through the full NWCC consensus process. Publication does not presume that all Members have reviewed the content of the document.

Since 1994, the NWCC has provided a neutral forum for a wide range of stakeholders to pursue the shared objective of developing environmentally, economically, and politically sustainable commercial markets for wind power in the United States. The NWCC forum provides opportunities for dialogue among lawmakers, public agencies and regulators, conservationists, and industry to discuss and develop unbiased and authoritative publically-available information on siting wind power.

The mission of the NWCC Wildlife Workgroup is to identify, define, discuss, and through broad stakeholder involvement and collaboration address wind-wildlife and wind-habitat interaction issues to promote the shared objective of developing commercial markets for wind power in the United States.

The NWCC published *Studying Wind Energy/Bird Interactions: A Guidance Document* in 1999. In the intervening 12 years much has been learned about the impacts of wind energy development on wildlife and their habitat. In consideration of this increase in knowledge, the NWCC published this expanded resource document. In addition to updating the methods and metrics available for studying wind energy and bird interactions, this resource document broadens its focus to include other wildlife, particularly bats, provides an abundance of case studies illustrating the application of methods and metrics, and introduces the concept of a decision framework.

For more information on the NWCC, please visit www.nationalwind.org.

# DISCLAIMER

Any specific technologies or vendors mentioned in this Guide are either included as examples or as references to work carried out using these technologies/vendors. The mention of specific technologies is not an endorsement of these over other technologies.

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# CHAPTER 1: INTRODUCTION

# INTRODUCTION

A desire to maximize the knowledge gained from the emerging study of wind energy/wildlife interactions prompted the National Wind Coordinating Collaborative (NWCC; http://www.nationalwind.org) to publish *Studying Wind Energy/Bird Interactions: A Guidance Document* (Anderson et al. 1999). As concern over potential impacts to bats emerged as a significant issue for renewable energy, the NWCC supported the publication of *Assessing Impacts of Wind Energy Development on Nocturnally Active Birds and Bats: A Guidance Document* (Kunz et al. 2007a). Subsequent to the publication of Anderson et al. (1999), much has been learned about the impacts of wind energy development on wildlife and their habitat. In consideration of this increase in knowledge and of new methods and metrics that have been developed, the NWCC published this resource document that expands on Anderson et al. (1999). While Anderson et al. (1999) focused on the study of wind energy impacts to birds, this resource document broadens its focus to include other wildlife, particularly bats. This document provides a review of the available methods and metrics and makes suggestions regarding their application. Notwithstanding, our recommendations should not be considered prescriptive as all sites are unique to some extent, and methods, metrics, and protocols by which they are applied should be adjusted to each individual situation.

The energy from wind was first used to generate electricity in the United States nearly 100 years ago. In 1999, commercial wind energy facilities existed in 15 states. As of 2005, wind facilities had expanded to 30 states (http://www.awea.org). By November 2008, 21,017 megawatts (MW) of wind energy installed capacity existed in the United States, with an additional 8,584 MW under construction. In 2008, the United States Department of Energy (USDOE) published a report suggesting that it is technically feasible to use wind energy to generate 20% of the nation's electricity demand – approximately 3,000,000 MW – if significant challenges are overcome (USDOE 2008). By the end of 2010, the United States had a wind energy capacity of 40,180 MW, with an additional 5,600 MW of wind energy under construction in the first quarter of 2011 (www.awea.org).

The use of wind energy also is growing rapidly in many other countries, having reached a capacity potential of over 47,000 MW worldwide in 2004 (http://www.awea.org); by the end of 2010, this had increased to over 196,000 MW of capacity worldwide (www.wwindea.org). Whereas wind energy, like other renewable energy resources, offers the prospect of significant environmental benefits, the effects of wind energy developments on birds, bats and other wildlife and their habitat have raised important legal and ecological issues in the permitting and operation of wind facilities.

Wind energy developers must consider a multitude of issues, including potential impacts on wildlife, when making the decision to pursue a project (www.awea.org/sitinghandbook/). The developer must first look for areas with abundant, reliable wind in a region where there is a market for wind-generated electricity. Project proponents then look for obtainable sites within that area that have cost-effective access and transmission capability. Once these preliminary data have been gathered, project proponents begin to look at the potential permitting issues they will face. One of these permitting issues is the potential effects the facility may have on wildlife and their habitat. This document addresses the wildlife and wildlife habitat component of this siting process.

## PURPOSE AND SCOPE OF THIS DOCUMENT

This document is intended as a guide to persons involved in designing, conducting, or requiring wind energy/wildlife interaction studies. The document follows a general framework for progressing through the decision process for a proposed wind project and a guide to methods and metrics for use in the necessary studies. This guide is relevant to the study of any wildlife species, although our focus is on birds and bats. Specifically, our aims are to:

1. Describe a potential framework that utilizes the basic concepts of risk-based decisions explicitly addressing issues associated with the effects on wildlife, particularly birds and bats, from the development and operation of wind energy facilities, in the pre- and post-construction phases of the development. A framework should provide a structure for focusing scientific principles and critical thinking toward the goal of effective environmental management, and integrating the views of diverse scientists, regulators, and public participants. A framework also should be useful as a decision tool to support regulatory decision making.
2. Provide a reference document for use in the production of a body of scientific information adequate to:
   - assess the suitability of a proposed wind facility site with regard to species of concern, including the potential for fatalities and for habitat loss;
   - assess the potential effects of a proposed wind energy facility on species of concern;
   - evaluate the actual effects of the implementation of wind energy technology on wildlife; and,
   - evaluate the effectiveness of measures taken to avoid, minimize, or offset significant adverse impacts and risk reduction management actions to reduce future impacts.
3. Provide sufficiently detailed and clearly understandable methods, metrics, and study designs for use in the study of wind energy/wildlife interactions.
4. Promote efficient, cost-effective and consistent study designs, methods, and metrics that will produce comparable data that could reduce the overall need for future studies.
5. Provide study designs and methods for the collection of information useful in reducing potential risk to wildlife in existing and future wind facilities.

Using generally agreed-upon and scientifically appropriate methods and metrics should help to enhance both the *credibility* and the *comparability* of study results, including the results of studies conducted at different sites with different study objectives.

The benefits of achieving these objectives are numerous. If study methods and metrics are generally agreed-upon, stakeholders can focus on the implications of study results rather than on debating the validity of the data and how they were obtained. If different studies generate comparable results, the total set of wind energy/wildlife interaction data will be increased. This in turn should help in understanding the differences and similarities among wind energy developments, in anticipating potential wildlife issues at yet-to-be-developed wind energy sites, and in generating a body of knowledge about how wind energy development and operation affects wildlife that can be disseminated to the public. It should also lead to a more efficient use of research and monitoring budgets.

It is neither possible nor appropriate to provide a detailed “cookbook” approach to every site-specific situation. Not all jurisdictions will require the same level of information on wildlife in conjunction with permitting a wind energy development, and each site will be unique to some extent. Many situations will require site-specific knowledge and expert recommendations as to which study design and methods are most appropriate. Notwithstanding, when wildlife studies are conducted the information in this document can be used to develop protocols specifically designed for each site.

This document is an update of Anderson et al. (1999). It provides an overview of wind energy/wildlife interactions, updated technical discussion of the basic concepts and tools for studying these wind energy interactions, and extensive case studies illustrating the application of many of these tools. Establishing standard metrics, methods, and study designs does not reduce the potential for adverse impacts, mitigate impacts, or guarantee a siting permit. It can help ensure that credible, acceptable, scientifically rigorous information is gathered wherever such information is required for wind energy site development.

While the list of metrics provided in this document is not exhaustive, the technical and biological information needs and approaches presented in this document can support informed decisions regardless of the size of the wind energy development project or the number of species and individuals potentially affected. These methods and metrics provide the basis both for assessing risk and for estimating impacts to wildlife. Nevertheless, wind energy project permitting, whether federal, state or local, may focus primarily on impacts prediction. Thus, studies should always be designed to provide information that helps the decision makers (permitting authorities) determine whether risk and/or impacts are likely to be significant, and whether mitigation measures, defined as avoidance, minimization or compensatory mitigation (replacement), are appropriate in the permit decision process.

For each of the methods and metrics we describe, we will attempt to point out their relative advantages, disadvantages, and underlying assumptions. In practice, project-specific protocols should be developed to accomplish specific study objectives. The optimal protocol will vary depending on the study objective and the amount and quality of preexisting information.

The appropriate study methods will vary depending on whether the primary species of interest is large (e.g., raptors, ungulates) or small (e.g., passerines, bats), nocturnal (e.g., bats, rodents, owls) or diurnal, migratory or resident, and so on. Methods also will vary depending on the objectives of the study. Study objectives must be clearly defined in order to determine the appropriate study design. The intent of this document is not to advise regulators on what the objectives of a study of wildlife impact should be, but rather to provide a guide on how to conduct a scientifically defensible study that achieves specified objectives, using methods and metrics that can meaningfully be compared against an agreed-upon benchmark.

## HISTORICAL PERSPECTIVE

Most of the attention historically has been focused on fatalities of birds at wind facilities, and especially on raptors in the United States (Anderson and Estep 1988; Estep 1989; Howell and Noone 1992; Orloff and Flannery 1992; Hunt 1995; Howell 1995; Smallwood and Thelander 2004b, 2005).

The detection of dead raptors at the Altamont Pass Wind Resource Areas (APWRA) (Anderson and Estep 1988; Estep 1989) triggered concern on the part of regulatory agencies, environmental and conservation groups, resource agencies, wind power companies, and electric utilities. This led the California Energy Commission and the planning departments of Alameda, Contra Costa, and Solano counties to commission the first extensive study of bird fatality at the APWRA (Orloff and Flannery 1992).

Prior to the mid-1990s other North American and European studies of wind energy/bird interactions documented deaths of songbirds (Orloff and Flannery 1992, Pearson 1992, Winkelman 1994, Higgins et al. 1995, Anderson et al. 1996) and waterbirds (Pearson 1992, Winkelman 1994). Research at Tarifa, Spain identified a high fatality rate for the griffon vulture (*Gyps fulvus*) (Martí 1994). These early studies also found that bats were killed at wind energy facilities (e.g., Higgins et al. 1995).

In 1992, the California Energy Commission and Pacific Gas and Electric Company sponsored a wind energy/bird interaction workshop focusing on wind energy effects on birds. This workshop convened interested parties to discuss the issue and its evaluation, thus taking an initial step toward the development of a nationwide approach. A research program directed by Kenetech Windpower, Inc. focused on the sensory and behavioral aspects of wind energy/bird interactions and represented another significant early effort to address the avian fatality issue. At the same time, the USDOE/National Renewable Energy Laboratory (NREL; http://www.nrel.gov/) initiated a program to identify and prioritize research needs, provide technical advice, and fund or cost-share numerous research projects.

The NWCC was formed as a partnership of experts and interested parties in 1994 to provide a neutral forum for a wide range of stakeholders. Funded by the US Department of Energy, the NWCC was established with the objective of developing environmentally, economically, and politically sustainable commercial markets for wind power in the United States. The NWCC focused on issues that potentially affected the use of wind power for the generation of electricity including wildlife and habitat impacts associated with the development of wind power.

In July 1994, the NWCC convened a national workshop in Denver, Colorado. Sponsored by NREL, USDOE, AWEA, National Audubon Society (Audubon), Electric Power Research Institute (EPRI), and Union of Concerned Scientists, the workshop examined existing information and concern about wind energy/bird interactions. One major focus was on systematizing the search for the factors responsible for avian deaths from wind energy facilities, and on placing efforts to reduce avian fatality on a firm, scientific basis (Proceedings of the National Avian Windpower Planning Meeting [NAWPM] 1995). Since that time, there have been additional NWCC planning meetings, research meetings and other collaborative efforts designed to advance the understanding of the impact of wind energy development on wildlife (NWCC Wildlife Workgroup; http://www.nationalwind.org/issues/wildlife.aspx).

Shortly after the first planning meeting, the NWCC formed an Avian Subcommittee to carry forward the work, begun at the 1994 NWCC workshop, of identifying and setting priorities for wind energy/bird interaction studies. The Subcommittee provided advice to funding agencies, promoted communication among participants in wind energy developments regarding approaches to resolving wind energy/bird conflicts, and facilitated the development of standard protocols for conducting wind energy/bird interaction studies. In January of 2003, primarily because of increasing concern over the number of bat fatalities occurring at modern facilities, the Avian Subcommittee changed its name to the Wildlife Workgroup (WW) and changed its focus to consider all wildlife issues relevant to wind energy development.

The NWCC felt that interested parties needed a better understanding of the effect of wind energy development on birds and whether fatality levels and risk vary from one WRA to another around the nation. Yet definitive research results on these complex questions require numerous studies over a period of several years – studies that often are field-intensive, time-consuming, and costly.

In September, 1995, the Avian Subcommittee sponsored a second national workshop in Palm Springs, California, to facilitate communication among avian researchers, regulators, and groups needing scientific information to review wind energy development proposals. An outcome of this meeting was the recommendation that a group of ornithologists, statisticians, and environmental risk specialists develop a set of study protocols and measures of wind energy/bird interactions that could be adopted by the NWCC; *Studying Wind Energy/Bird Interactions: A Guidance Document* (Anderson et al. 1999) was the result of that effort. It was hoped that this document would facilitate the comparison of results from wind energy/bird studies in different areas, and that it would lead to improved understanding of potential causal factors in wind energy/bird interactions.

Produced by the Avian Subcommittee, Anderson et al. (1999) was reviewed by a wide range of stakeholders and was endorsed by the NWCC as a valuable reference that could be used throughout the nation. A separate NWCC document, *Permitting of Wind Energy Facilities Handbook* (NWCC 1998), was developed "to help stakeholders make permitting decisions in a manner which assures necessary environmental protection and responds to public needs." The *Handbook* provided an overview of the basic features of a wind project and discussed the permitting process. It also described many of the issues that may arise in the permitting process and provided trade-off considerations and strategies for dealing with the issues. The potential impact of wind development on bird resources of concern was one of these issues. *Permitting of Wind Energy Facilities* also provided information on the steps and participants involved in the permitting process of a wind facility project.

Results of the early research at the APWRA increased scrutiny and caution during the permitting of new wind facility developments, often resulting in costly delays. Subsequent research at Tehachapi, California, found much lower raptor fatalities than at APWRA (Anderson et al. 2004) but also indicated that the Tehachapi Pass WRA and the APWRA differed—most importantly, that raptor use may be much lower in the Tehachapi Pass WRA. Yet, this comparison suffered from the fact that protocols and study objectives were substantially different among these studies. Over time, additional research results from other United States avian studies provided some support for the belief that not all wind developments would result in the same level of bird fatalities as at the APWRA. Recent results from avian research at other wind sites where many of these metrics are comparable suggest that wind turbines can be sited in a manner that reduces the potential for bird fatalities (NRC 2007). However, the comparability of metrics has been confounded by the use of different fatality estimators and small sample sizes, some of which may be biased severely low or high, potentially leading to misleading conclusions. For example, the number of studies at facilities in the mountains of the eastern U.S. are very limited and one, the Buffalo Mountain, Tennessee, study (Fiedler 2004) included in the NRC (2007) report, contained a very small sample size, only 3 turbines, and used an early estimator (Johnson 2005).

While fatality impacts have been the primary focus of most wind energy and wildlife studies, habitat impacts from wind energy development are also of concern, especially in the Midwest (e.g., Shaffer and Johnson 2008) and the Pacific Northwest (e.g., Erickson et al. 2004). Habitat impacts are of particular concern where native habitat has been reduced due to various land uses and where wind resources and the remaining native habitat significantly overlap.

Subsequent to publication of Anderson et al. (1999), the Avian Subcommittee changed its name and focus to all wildlife, and broadened its perspective to include potential habitat impacts. While the information on methods and study designs in Anderson et al. (1999) were generally transferable to all species, the information was deficient in the coverage of methods and metrics for nocturnally active species and to a lesser extent to the study of habitat impacts. The deficiencies related to nocturnally active species were partially addressed at the November 2006 Wildlife Workgroup meeting when NWCC sponsored the development of nocturnal methods and metrics guidelines (Kunz et al. 2007a), adopted herein as Appendix A.

## REVIEW OF WIND ENERGY FACILITY HAZARDS TO WILDLIFE

The following review is focused principally on birds and bats and is primarily based on three recent reviews, the National Academies' NRC report on *Environmental Impact of Wind Energy Projects* (NRC 2007), The Wildlife Society's white paper on the *Impact of Wind Energy Facilities on Wildlife* (Arnett et al. 2007b), and Kunz et al.'s (2007b) review of the *Ecological Impacts of Wind Energy Development on Bats*.

### Fatalities

Wind turbines cause fatalities of birds and bats through collision, typically assumed to be with the turbine blades. There is, however, some evidence that some percentage of bat fatalities result from rapid decompression, often called barotrauma (Baerwald et al. 2008), resulting when bats encounter suddenly changing pressures near the rapidly moving blade tip and outer portions of the blade. Species differ in their vulnerability to collision. Passerines are the most common species occurring within a wind facility and make up the vast majority of avian fatalities found at modern wind facilities. Nevertheless, individuals of other species (e.g. raptors) appear to be at greater risk of collision, when risk is defined as the probability of collision given exposure to a wind facility (NRC 2007, Arnett et al. 2007b). Avian fatality rates are fairly consistent across the country at most facilities that have been studied with appropriate methods (Figure 1.1); that is, 42 of the 63 studies report fatalities of all birds at less than or equal to three fatalities/MW/year. However, caution should be exercised when comparing fatality estimates from different studies when different estimators were used. Among the 63 studies listed in Figure 1.1, different estimators were used, and some of the estimators have been shown to be biased low, while others may be biased high. The comparison of fatality estimations is further compounded by the varying search intensities, study lengths, study timing, the size of the search areas, and biases from unaccounted crippling losses (Huso 2009, 2010; Manville 2009). Some of these biases could lead to under-counting of carcasses (e.g., plot size). However, treating all bird fatality evidence as wind turbine kills could lead to an overestimate. For example, Johnson et al. (2000a) found a background mortality of approximately 33%.

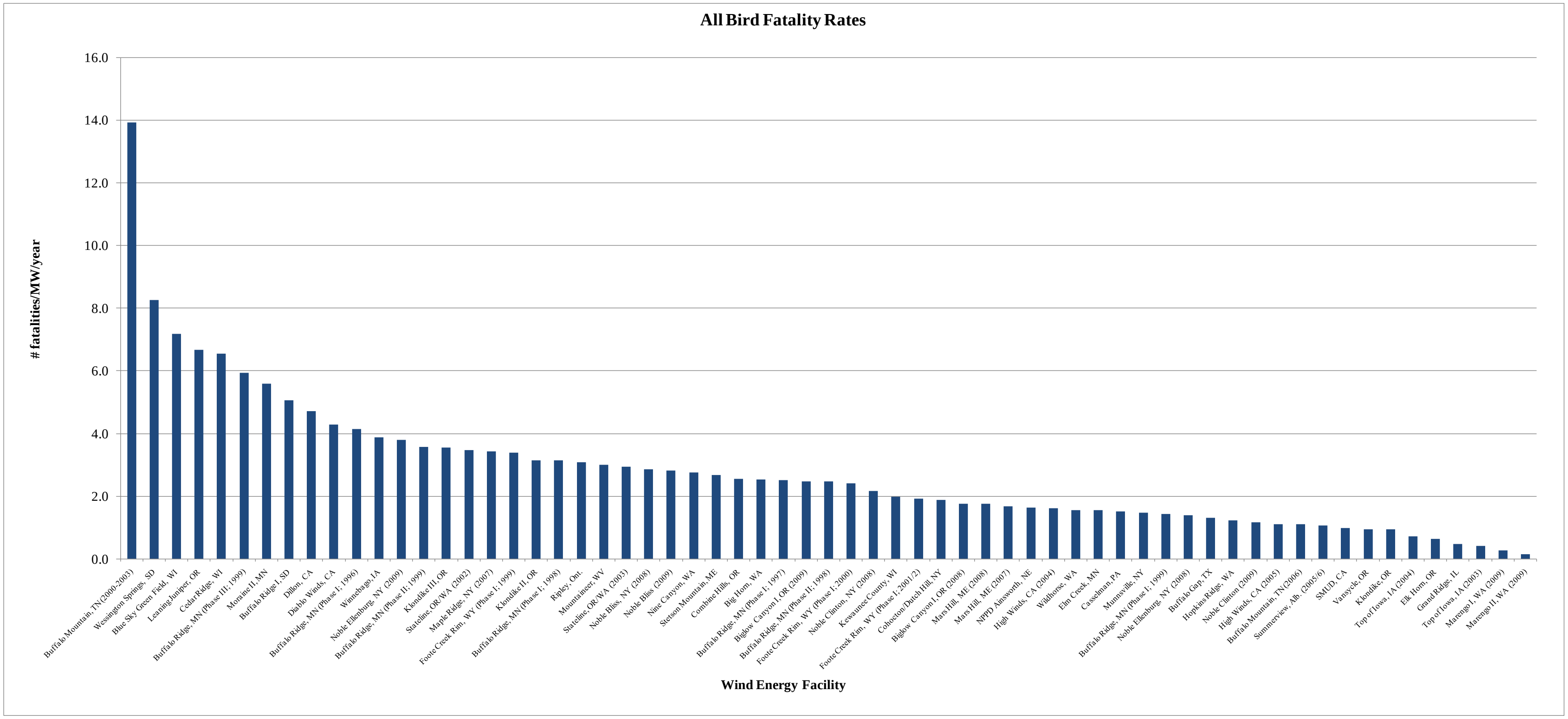


**Figure 1.1. All bird fatalities per nameplate MW per year at North American facilities with published fatality data.**

Data from the following sources:

| | | | | | |
|---|---|---|---|---|---|
| Buffalo Mountain, TN (2000-2003) | Nicholson et al. 2005 | Combine Hills, OR | Young et al. 2006 | Munnsville, NY | Stantec 2008b |
| Blue Sky Green Field, WI | Gruver et al. 2009 | Big Horn, WA | Kronner et al. 2008 | Buffalo Ridge, MN (Phase I; 1999) | Johnson et al. 2000a |
| Leaning Juniper, OR | Gritski et al. 2008 | Buffalo Ridge, MN (Phase I; 1997) | Johnson et al. 2000a | Noble Ellenburg, NY (2008) | Jain et al. 2009a |
| Buffalo Ridge, MN (Phase III; 1999) | Johnson et al. 2000a | Biglow Canyon I, OR (2009) | Jeffrey et al. 2009a | Buffalo Gap, TX | Tierney 2007 |
| Diablo Winds, CA | WEST 2008 | Buffalo Ridge, MN (Phase II; 1998) | Johnson et al. 2000a | Hopkins Ridge, WA | Young et al. 2007 |
| Buffalo Ridge, MN (Phase I; 1996) | Johnson et al. 2000a | Foote Creek Rim, WY (Phase I; 2000) | Young et al. 2003b | Noble Clinton (2009) | Jain et al. 2010b |
| Buffalo Ridge, MN (Phase II; 1999) | Johnson et al. 2000a | Noble Clinton, NY (2008) | Jain et al. 2009b | High Winds, CA (2005) | Kerlinger et al. 2006 |
| Stateline, OR/WA (2002) | Erickson et al. 2004 | Kewaunee County, WI | Howe et al. 2002 | Buffalo Mountain, TN (2006) | Fiedler et al. 2007 |
| Maple Ridge, NY (2007) | Jain et al. 2008 | Foote Creek Rim, WY (Phase I; 2001/2002) | Young et al. 2003b | Summerview, Alb. (2005/2006) | Brown and Hamilton 2006 |
| Foote Creek Rim, WY (Phase I; 1999) | Young et al. 2003b | Cohocton/Dutch Hill, NY | Stantec 2010 | SMUD, CA | URS et al. 2005 |
| Klondike II, OR | NWC and WEST 2007 | Biglow Canyon I, OR (2008) | Jeffrey et al. 2009a | Vansycle, OR | Erickson et al. 2000a |
| Buffalo Ridge, MN (Phase I; 1998) | Johnson et al. 2000a | Mars Hill, ME (2008) | Stantec 2009a | Klondike, OR | Johnson et al. 2003 |
| Mountaineer, WV | Kerns and Kerlinger 2004 | Mars Hill, ME (2007) | Stantec 2008a | Top of Iowa, IA (2004) | Jain 2005 |
| Stateline, OR/WA (2003) | Erickson et al. 2004 | NPPD Ainsworth, NE | Derby et al. 2007 | Elk Horn, OR | Jeffrey et al. 2009b |
| Noble Bliss, NY (2008) | Jain et al. 2009d | High Winds, CA (2004) | Kerlinger et al. 2006 | Grand Ridge, IL | Derby et al. 2010g |
| Nobel Bliss, NY (2009) | Jain et al. 2010a | Wild Horse, WA | Erickson et al. 2008 | Top of Iowa, IA (2003) | Jain 2005 |
| Nine Canyon, WA | Erickson et al. 2003b | Elm Creek, MN | Derby et al. 2010d | Marengo I, WA (2009) | URS Corporation 2010a |
| Stetson Mountain, ME | Stantec 2009b | Casselman, PA | Arnett et al. 2009b | Marengo II, WA (2009) | URS Corporation 2010b |

There are also no clear-cut differences in avian fatality rates among different land cover types. In general, avian fatality rates appear similar in agricultural landscapes (37 facilities; 2.80/MW/study period), grassland (20 facilities; 2.41/MW/study period), and forested landscapes (9 facilities; 3.27/MW/study period). Nevertheless, there is some indication that passerine fatality rates may be higher in the mid-western (e.g., Buffalo Ridge, Phase III; 5.93/MW/study period) and eastern United States (e.g., Maple Ridge; 5.81/MW/study period), particularly at facilities in mountain settings (Buffalo Mountain 2000-2003; 13.93/MW/study period). Unfortunately, the number of facilities in the eastern United States makes testing the hypothesized relationship between landscape and fatality rates impossible at the present time. For example, while the Buffalo Mountain facility (2000-2003, 13.93/MW/study period) is a mountain top facility in the east and has the highest reported fatality rate, this facility contained only three turbines during the study (Nicholson 205). The Mountaineer facility (3.00/MW/study period) is also a mountain top facility with 44 turbines, but the fatality rate is similar to that estimated for facilities in western grassland and agricultural settings. Interestingly, a subsequent study of an expanded Buffalo Mountain facility (Fiedler et al. 2007) found a much lower fatality rate in 2005 (1.10/MW/study period).

The relatively high raptor fatality rate at the APWRA (Orloff and Flannery 1996) was the original catalyst that raised public concern over the impact of wind energy development on birds. While raptor fatality rates are relatively low at most modern wind energy facilities (Figure 1.2), raptor fatalities are still much higher relative to the number of individuals exposed to collisions than are passerines (NRC 2007). Of the 36 studies providing annual estimates of fatalities corrected for detection bias, raptor fatalities ranged from zero at several facilities to approximately 0.87/MW/study period at the Diablo Winds, California, facility (WEST 2008). Even though the raptor fatality rates reported at APWRA are still the highest of those facilities having been studied, raptor fatality rates in California in general are much higher than reported at other facilities around the country. As with fatality rates for all birds, there were no clear differences in raptor fatality rates among different land cover types.

Bat fatalities were initially found incidental to the study of avian fatalities. However, as more sites were studied it became obvious that bat fatalities were a common phenomenon at wind energy facilities (Figure 1.3). Of the 66 current studies providing annual estimates of bat fatalities, most studies (54) reported bat fatality rates of less than 10/MW/study period, ranging from 0.07/MW/study period at the SMUD facility in California to 39.7/MW/study period at Buffalo Mountain (2006) in Tennessee. Arnett et al. (2008) reviewed 21 studies from 19 different wind energy facilities in five regions in the United States and one province in Canada. The review illustrated the wide range of protocols used in estimating bat fatality rates and recommended caution in comparing the results of these studies. Arnett et al. (2008) summarized bat fatalities as highest at wind energy facilities located on forested ridges in the eastern U.S. (14.9 – 53.3/MW/study period) and lowest in the Rocky Mountain and Pacific Northwest regions (0.8 – 2.5/MW/study period). However, the researchers caution that bat fatalities can be highly variable even among facilities in close proximity.

The highest bat fatality rates in the United States have been reported at three facilities in the mountains in the eastern part of the country, and it has been assumed that facilities constructed in this landscape would present the most risk to bats. Recent evidence from studies in the Northeast (e.g., Maple Ridge; Jain et al. 2007), Upper Midwest (Top of Iowa; Jain 2005), Cedar Ridge in Wisconsin (BHE Environmental 2010), Blue Sky Green Fields in Wisconsin (Gruver et al. 2009), and in southern Alberta, Canada (Baerwald 2008), however, suggest that facilities constructed in agricultural landscapes also may result in relatively high bat fatality rates.

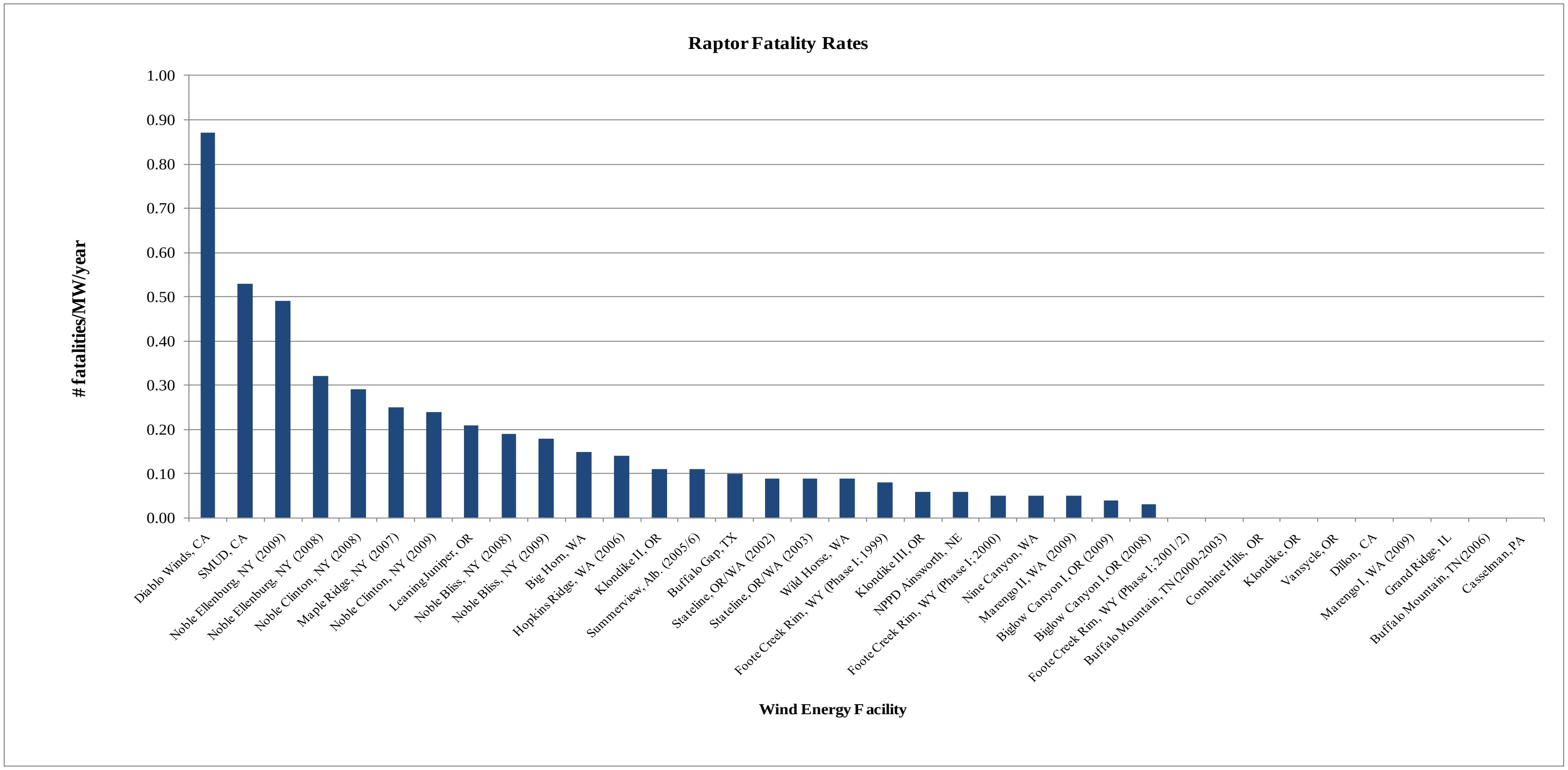


**Figure 1.2. Raptor fatalities per nameplate MW per year at North American facilities with published fatality data.**

Data from the following sources:

| | | | | | |
|---|---|---|---|---|---|
| Diablo Winds, CA | WEST 2008 | Klondike II, OR | NWC and WEST 2007 | Biglow Canyon I, WA (2009) | Jeffrey et al. 2009a |
| SMUD, CA | URS et al. 2005 | Summerview, Alb. (2005/2006) | Brown and Hamilton 2006 | Biglow Canyon I, WA (2008) | Jeffrey et al. 2009b |
| Noble Ellenburg, NY (2009) | Jain et al. 2010c | Buffalo Gap, TX | Tierney 2007 | Foote Creek Rim, WY (Phase I; 2000/2002) | Young et al. 2003b |
| Noble Ellenburg, NY (2008) | Jain et al. 2009a | Stateline, OR/WA (2002) | Erickson et al. 2004 | Buffalo Mountain, TN (2000-2003) | Nicholson 2003, Nicholson et al. 2005 |
| Noble Clinton, NY (2008) | Jain et al. 2009b | Stateline, OR/WA (2003) | Erickson et al. 2004 | Combine Hills, OR | Young et al. 2006 |
| Maple Ridge, NY (2007) | Jain et al. 2008 | Wild Horse, WA | Erickson et al. 2008 | Klondike, OR | Johnson et al. 2003 |
| Noble Clinton, NY (2009) | Jain et al. 2010b | Foote Creek Rim, WY (Phase I; 1999) | Young et al. 2003b | Vansycle, OR | Erickson et al. 2000a |
| Leaning Juniper, OR | Gritski et al. 2008 | Klondike III, OR | Gritski et al. 2009 | Dillon, CA | Chatfield et al. 2009 |
| Noble Bliss, NY (2008) | Jain et al. 2009d | NPPD Ainsworth, NE | Derby et al. 2007 | Marengo I, WA (2009) | URS Corporation 2010a |
| Noble Bliss, NY (2009) | Jain et al. 2010a | Foote Creek Rim, WY (Phase I; 2000) | Young et al. 2003b | Grand Ridge, IL | Derby et al. 2010g |
| Big Horn, WA | Kronner et al. 2008 | Nine Canyon, WA | Erickson et al. 2003b | Buffalo Mountain, TN (2006) | Fiedler et al. 2007 |
| Hopkins Ridge, WA | Young et al. 2007 | Marengo II, WA (2009) | URS Corporation 2010b | Casselman, PA | Arnett et al. 2009b |

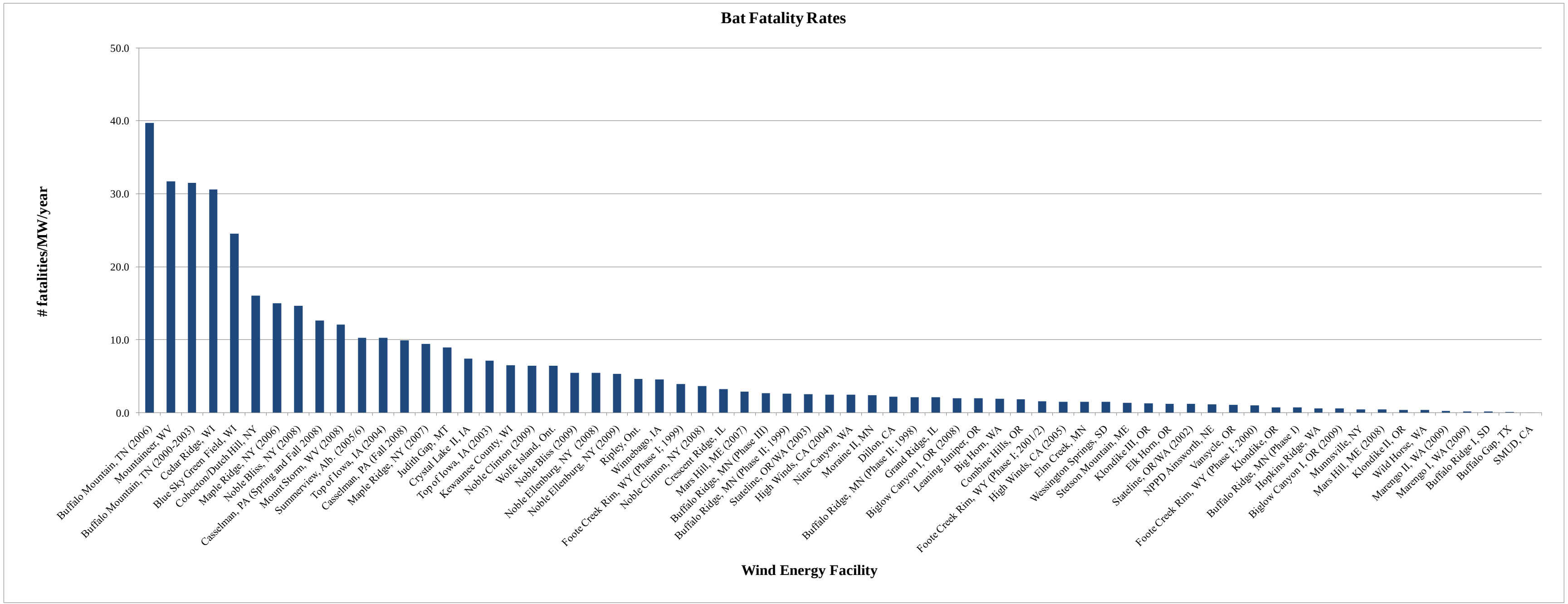


**Figure 1.3. Bat fatalities per nameplate MW per year at North American facilities with published fatality data.**

Data from the following sources:

| | | | | | |
|---|---|---|---|---|---|
| Buffalo Mountain, TN (2006) | Fiedler et al. 2007 | Noble Ellenburg, NY (2009) | Jain et al. 2010c | Elm Creek, MN | Derby et al. 2010d |
| Mountaineer, WV | Kerns and Kerlinger 2004 | Ripley, Ont. | Jacques Whitford 2009 | Wessington Springs, SD | Derby et al. 2010f |
| Cedar Ridge, WI | BHE Environmental 2010 | Winnebago, IA | Derby et al. 2010b | Stetson Mountain, ME | Stantec 2009b |
| Buffalo Mountain, TN (2000-2003) | Nicholson et al. 2005 | Foote Creek Rim, WY (Phase I; 1999) | Young et al. 2003b | Klondike III, OR | Gritski et al. 2009 |
| Blue Sky Green Field, WI | Gruver et al. 2009 | Noble Clinton, NY (2008) | Jain et al. 2009b | Elk Horn, OR | Jeffrey et al. 2009b |
| Cohocton/Dutch Hill, NY | Stantec 2010 | Crescent Ridge, IL | Kerlinger et al. 2007 | Stateline, OR/WA (2002) | Erickson et al. 2004 |
| Maple Ridge, NY (2006) | Jain et al. 2007 | Mars Hill, ME (2007) | Stantec 2008a | NPPD Ainsworth, NE | Derby et al. 2007 |
| Noble Bliss, NY (2008) | Jain et al. 2009d | Buffalo Ridge, MN (Phase III) | Johnson et al. 2000a | Vansycle, OR | Erickson et al. 2000a |
| Casselman, PA (Spring & Fall 2008) | Arnett et al. 2009b | Buffalo Ridge, MN (Phase II; 1999) | Johnson et al. 2000a | Foote Creek Rim, WY (Phase I; 2000) | Young et al. 2003b |
| Mount Storm, WV (2008) | Young et al. 2009 | Stateline, OR/WA (2003) | Erickson et al. 2004 | Klondike, OR | Johnson et al. 2003 |
| Summerview, Alb. (2005/2006) | Brown and Hamilton 2006 | High Winds, CA (2004) | Kerlinger et al. 2006 | Buffalo Ridge, MN (Phase I) | Johnson et al. 2000a |
| Top of Iowa, IA (2004) | Jain 2005 | Nine Canyon, WA | Erickson et al. 2003b | Hopkins Ridge, WA | Young et al. 2007 |
| Casselman, PA (Fall 2008) | Arnett et al. 2009a | Moraine II, MN | Derby et al. 2010e | Biglow Canyon I, OR (2009) | Jeffrey et al. 2009a |
| Maple Ridge, NY (2007) | Jain et al. 2008 | Dillon, CA | Chatfield et al. 2009 | Munnsville, NY, | Stantec 2008b |
| Judith Gap, MT | TRC 2008 | Buffalo Ridge, MN (Phase II; 1998) | Johnson et al. 2000a | Mars Hill, ME (2008) | Stantec 2009a |
| Crystal Lake II, IA | Derby et al. 2010a | Grand Ridge, IL | Derby et al. 2010g | Klondike II, OR | NWC and WEST 2007 |
| Top of Iowa, IA (2003) | Jain 2005 | Biglow Canyon I, OR (2008) | Enk et al. 2010 | Wild Horse, WA | Erickson et al. 2008 |
| Kewaunee County, WI | Howe et al. 2002 | Leaning Juniper, OR | Gritski et al. 2008 | Marengo II, WA (2009) | URS Corporation 2010b |
| Noble Clinton, NY (2009) | Jain et al. 2010b | Big Horn, WA | Kronner et al. 2008 | Marengo I, WA (2009) | URS Corporation 2010a |
| Wolf Island, Ont. | Stantec, Ltd. 2010 | Combine Hills, OR | Young et al. 2006 | Buffalo Ridge I, SD | Derby et al. 2010c |
| Noble Bliss, NY (2009) | Jain et al. 2010a | Foote Creek Rim, WY (Phase I; 2001/02) | Young et al. 2003b | Buffalo Gap, TX | Tierney 2007 |
| Noble Ellenburg, NY (2008) | Jain et al. 2009a | High Winds, CA (2005) | Kerlinger et al. 2006 | SMUD, CA | URS et al. 2005 |

Migratory tree-roosting bat species (*Lasiurus* spp. and *Lasionycteris noctivagans*) are the most common bat fatalities found at wind energy facilities. Publically-available fatality data from 70 wind energy facilities in North America shows that hoary bats (*Lasiurus cinereus*), silver-haired bats (*Lasionycteris noctivagans*), and eastern red bats (*Lasiurus borealis*) are the three most commonly found bat species during fatality studies, accounting for roughly 77% of all bat fatalities. Notwithstanding, *Myotis spp* comprised approximately 50% of the fatalities at a facility in Wisconsin (Gruver et al. 2009). Until recently, no endangered species had been reported being killed at existing wind energy facilities. However, in 2009 and again in 2010 a single Indiana bat fatality was discovered each September during bat migration at a facility in Indiana (Good et al. 2011).

Risks of fatalities to bats in the southwestern United States, especially in Texas, where large wind energy facilities exist and have been proposed, are largely unknown. However, the Brazilian free-tailed bat (*Tadarida brasiliensis*) made up a high proportion of bat kills at facilities studied within its range (41.3% in California [Kerlinger et al. 2006], 85.6% in Oklahoma [Piorkowski 2006], 94% in Texas [Miller 2008]). Piorkowski and O'Connell (2010) speculated that the higher rate of Brazilian free-tailed bat fatalities found in the Oklahoma study may have been due to the sites' proximity to a maternity colony. These results suggest that in the southwestern United States, the Brazilian free-tailed bat, a long-distance migrant that roosts colonially in caves, may be at greater risk than other colonial species in this region (e.g., eastern pipistrelles [*Pipistrellus subflavus*]).

**Factors Influencing Fatalities**

The factors influencing fatality rates remain poorly understood, but available evidence suggests that wildlife bird and bat fatality rates are a function of abundance, local concentrations, and behavioral characteristics of species, weather, and the characteristics of the wind energy facilities. Abundance likely interacts with behavior to influence exposure of birds to collisions, although the relative importance of these two factors is unknown and appears to vary among different groups of birds (Lucas et al. 2008). Raptors appear to be the bird group most vulnerable to collisions. On average, raptors constitute 6% of the reported fatalities at wind energy facilities, yet they are far less abundant than most other groups of birds (e.g., passerines). When collisions occur, raptor carcasses are more likely to be found than are the carcasses of smaller birds. In contrast, crows, ravens and vultures are among the most common bird species seen flying within the rotor swept area of turbines, yet they are seldom found during carcass surveys. Nocturnally migrating passerines are the most abundant species at most wind energy facilities, particularly during spring and fall migration, and are the most common fatalities reported by number among bird species. Migratory tree roosting bats are the most commonly reported bat fatalities below turbines, although little is known about the abundance, behavior, and the factors influencing the vulnerability of bats to collisions with wind turbines (Kunz et al. 2007b).

A preliminary analysis of data on fatality rates versus an index of abundance from publicly available studies suggests that raptor abundance explains a significant portion of the variability in fatality rates among facilities (Figure 1.4). Additional data are needed, particularly in areas with intermediate fatality rates, to confirm this relationship, but abundance is very likely one of the most important predictors of the risk of fatalities for raptors. Landscape features influence raptor density by concentrating prey or by providing favorable conditions for other activities such as nesting, feeding, and flying (e.g., updrafts for raptor soaring; (NRC 2007). Landscape features (e.g., woodlots, wetlands, and linear landscapes) also may influence the density of other birds and bats, but there is no clear-cut relationship between fatalities of other birds and bats and these features.

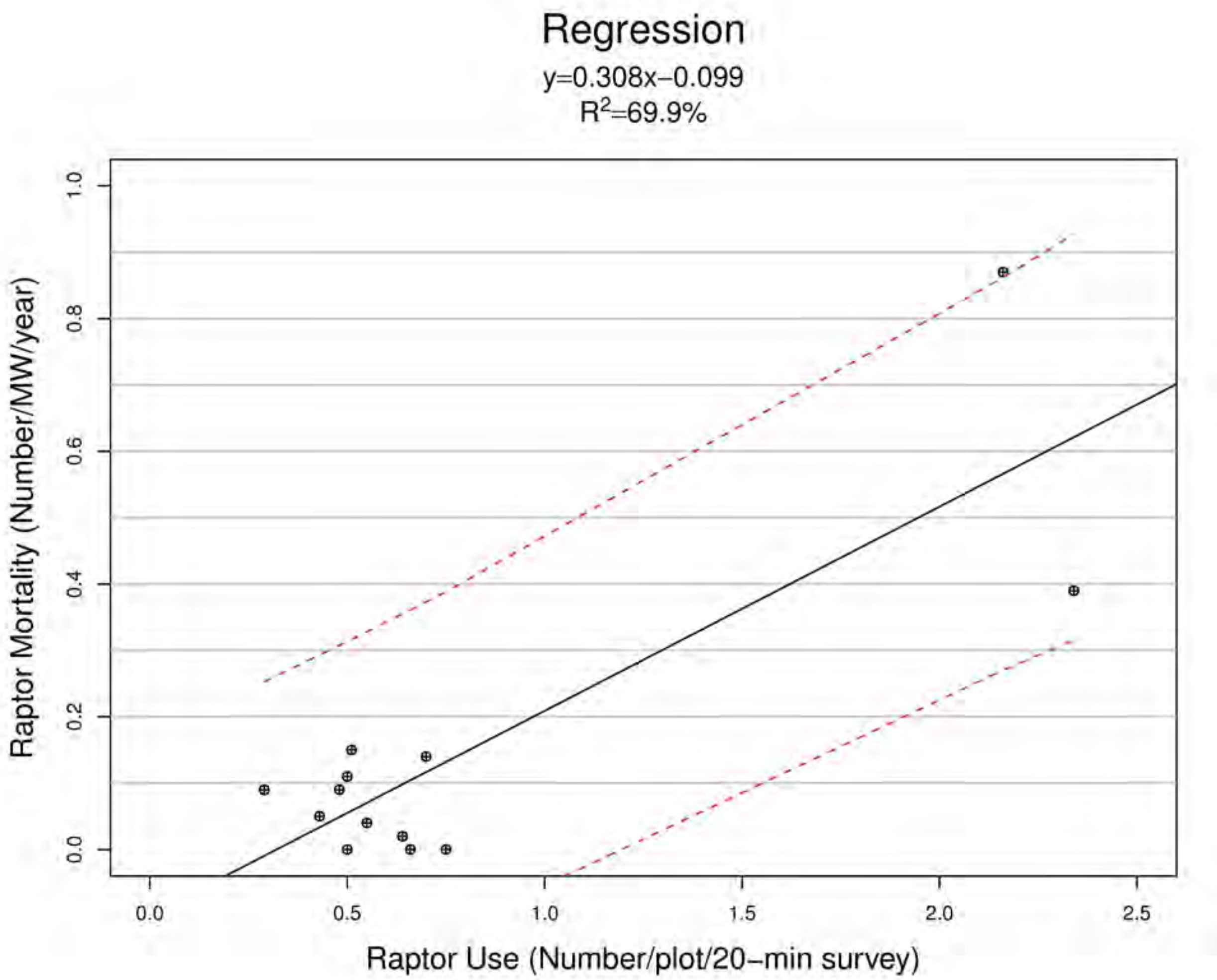


**Figure 1.4. Regression analysis comparing raptor use estimates versus estimated raptor mortality.**

Data from the following sources:

| Study and Location | Raptor Use | Source | Raptor Mortality | Source |
|---|---|---|---|---|
| Buffalo Ridge, MN | 0.64 | Erickson et al. 2002b | 0.02 | Erickson et al. 2002b |
| Combine Hills, OR | 0.75 | Young et al. 2003c | 0.00 | Young et al. 2005 |
| Diablo Winds, CA | 2.161 | WEST 2006 | 0.87 | WEST 2006 |
| Foote Creek Rim, WY | 0.55 | Johnson et al. 2000b | 0.04 | Young et al. 2003b |
| High Winds, CA | 2.34 | Kerlinger et al. 2005 | 0.39 | Kerlinger et al. 2006 |
| Hopkins Ridge, WA | 0.70 | Young et al. 2003a | 0.14 | Young et al. 2007 |
| Klondike II, OR | 0.50 | Johnson 2004 | 0.11 | NWC and WEST 2007 |
| Klondike, OR | 0.50 | Johnson et al. 2002 | 0.00 | Johnson et al. 2003 |
| Stateline, WA/OR | 0.48 | Erickson et al. 2002b | 0.09 | Erickson et al. 2002b |
| Vansycle, OR | 0.66 | WCIA and WEST 1997 | 0.00 | Erickson et al. 2002b |
| Wild Horse, WA | 0.29 | Erickson et al. 2003c | 0.09 | Erickson et al. 2008 |
| Zintel, WA | 0.43 | Erickson et al. 2002a | 0.05 | Erickson et al. 2002b |
| Bighorn, WA | 0.51 | Johnson and Erickson 2004 | 0.15 | Kronner et al. 2008 |

The characteristics of wind energy facilities (e.g., rotor swept area, height, support structure, lighting, number of turbines, etc.) may influence bird and bat fatalities. Newer, larger turbines installed on monopoles appear to cause fewer bird fatalities than the smaller, lattice-type turbines typically used during the initial development of wind energy in the United States (NRC 2007), although this has not been substantiated by controlled studies.

Scientists understand far less about the risk wind facilities pose to bats because the number of bats exposed to collisions is unknown. Assessing potential impacts is further complicated because the proximate and ultimate causes of bat fatalities at wind energy facilities are not fully understood (Baerwald et al. 2008, Cryan and Barclay 2009; Long et al. 2010a, b). Nevertheless, recent evidence suggests that fatalities increase as the number of bat vocalizations (as determined with acoustical detection devices) increases near turbines (Kunz et al. 2007a: 2467). Kunz et al. (2007b) identified eleven hypotheses regarding how, when, where and why bats are being killed at wind energy facilities. Cryan and Barclay (2009) further discussed hypotheses regarding the causes of bat fatalities at wind facilities. The hypotheses include:

- *Linear Corridor Hypothesis*. Construction of wind energy facilities along forested ridge tops creates clearings that form linear landscapes. Bats frequently use these linear landscapes during migration and while commuting and foraging (Limpens and Kapteyn 1991, Verboom and Spoelstra 1999, von Hensen 2004, Menzel et al. 2005), and thus may be placed at increased risk of being killed (Dürr and Bach 2004).
- *Roost Attraction Hypothesis*. Tree-roosting bats commonly seek roosts in tall trees (Pierson 1998, Kunz and Lumsden 2003, Barclay and Kurta 2007) and thus if wind turbines are perceived as potential roosts (Ahlén 2002, 2003, von Hensen 2004), their presence could contribute to increased risks of fatality when bats search for night roosts or during migratory stopovers.
- *Landscape Attraction Hypothesis*. Modifications of landscapes needed to install wind energy facilities, such as the construction of wide-access power corridors and the removal of trees to create clearings (usually 0.5-2 ha) around each turbine site, create conditions favorable for insects upon which bats feed (Lewis 1970, Grindal and Brigham 1998, von Hensen 2004). Thus, bats that are attracted to and feed on insects in these altered landscapes may be at an increased risk of being killed by wind turbines.
- *Low Wind Velocity Hypothesis*. Fatalities of aerial feeding and migrating bats are highest on nights during periods of low wind velocity (Fiedler 2004, Arnett 2005, von Hensen 2004, Baerwald et al. 2008), in part because aerial insects are most active under these conditions (Ahlén 2002, 2003).
- *Insect Attraction Hypothesis*. Flying insects are attracted to the heat produced by nacelles of wind turbines (Ahlén 2002, 2003; Corten and Veldkamp 2001; von Hensen 2004). As bats respond to high densities of flying insects near wind turbines, the risk of being struck by turbine blades may increase.
- *Visual Attraction Hypothesis*. Bats and their insect prey are attracted to lights placed on wind turbines as required by the United States Federal Aviation Administration (FAA), or to the reflection from white turbines under moonlit conditions, thus increasing the chances of collision and fatality as bats feed on insects (Arnett et al. 2005).

- *Acoustic Attraction Hypothesis*. Bats may be attracted to audible and/or ultrasonic sound produced by wind turbines (Schmidt and Joermann 1986, Ahlén 2002, 2003). Sounds produced by the turbine generator and the swishing sounds of rotating turbine blades may attract bats, thus increasing risks of collision and fatality.
- *Echolocation Failure Hypothesis.* Migrating and foraging bats may fail to detect wind turbines by echolocation, or miscalculate rotor velocity (Ahlén 2002, 2003, Bach and Rahmel 2004). If bats are unable to detect the moving turbine blades, they may be struck and killed directly.
- *Electromagnetic-Field Distortion Hypothesis*. If bats have receptors sensitive to magnetic fields (Buchler and Wasilewski 1985) and wind turbines produce complex, electromagnetic fields in the vicinity of the nacelle, the flight behavior of bats may be altered by these fields and thus increase the risk of being killed by rotating turbine blades.
- *Decompression Hypothesis.* Bats flying in the vicinity of turbines may experience rapid decompression (Dürr and Bach 2004; von Hensen 2004). Rapid pressure change may cause internal injuries and/or disorientation, thus increasing risk of death.
- *Thermal Inversion Hypothesis*. The altitude at which bats migrate and or feed may be influenced by thermal inversions, forcing them to the altitude of rotor swept areas (Arnett et al. 2005). The most likely impact of thermal inversions is to create dense fog in cool valleys, possibly concentrating both bats and insects on ridges, and thus encouraging bats to feed over the ridges on those nights, if for no other reason than to avoid the cool air and fog.

Cryan (2008) proposed an additional hypothesis suggesting that the large turbines appear as large trees to male tree-roosting bats and these bats are attracted to these large features in the hopes that females also will be attracted. None of these hypotheses have been tested to date and are not necessarily mutually exclusive, and several of the hypothesized factors might act together to produce the fatalities that have been reported (Kunz et al. 2007b; Johnson et al. 2007).

It has been hypothesized that the presence of the turbine, even with stationary blades, could increase risk to individual birds and bats, especially in periods of poor visibility (fog, rain, night, dusk or dawn; NRC 2007). Notwithstanding, of the 64 turbines studied by Kerns et al. (2005), bat fatalities were found at all turbines except one that was nonoperational during the study period, suggesting that moving blades are the primary cause of bat fatalities. Several studies have shown some apparent relationship between bat fatalities and weather (Arnett et al. 2008). In a study of two facilities in the northeastern United States, Kerns et al. (2005) found that most bat fatalities occurred immediately after a front during low wind conditions. It also has been hypothesized that operation during peak periods of bird and bat migration, such as during spring and fall, could increase the absolute number of deaths simply because of the large number of individuals passing through the area (NRC 2007).

### Population Effects

The effect of wind energy related fatalities on bird and bat populations is unknown at facilities, with one exception. Avian fatalities are relatively low at the existing facilities where studies have been conducted and it is unlikely that population impacts have occurred. Nevertheless, the lack of avian density estimates and other population characteristics, the lack of multi-year studies, and the lack of any estimates at most existing wind energy facilities makes it difficult to draw general conclusions about the effect of wind energy related fatalities on avian populations (NRC 2007). At the one site where population effects have been studied, Hunt (2002) found that the resident golden eagle population at the APWRA appeared to be self-sustaining, in spite of relatively high fatalities, although the effect of these fatalities on eagle populations wintering within and adjacent to the APWRA is unknown. Fatality rates of migratory tree bats appear to be relatively high in some landscapes (e.g., forested mountain ridges); however, without a better understanding of the population status of these species it is impossible to determine the biological significance of these fatalities. As the abundance of wind facilities increases, the potential for cumulative and significant population effects must be considered (NRC 2007), although the focus of concern will continue to be on local populations, where the potential for population effects is greatest.

**Habitat**

Habitat is a species-specific concept. That is, habitat should be discussed with reference to a specific species (Morrison et al. 2006). The following is a general discussion of what is known about wind energy development on wildlife habitat, although the discussion focuses primarily on birds.

Relatively little is known about wildlife habitat impacts from wind development, although there is a growing concern, particularly as development expands to native landscapes in the mid-western region of the United States. Potential wildlife habitat impacts from wind energy development include the direct loss of habitat and the loss of habitat due to displacement of wildlife from suitable habitat. Generally speaking, wind energy development has a relatively small permanent footprint, approximately 1 acre/turbine, and consequently the potential direct loss of wildlife habitat is low (NRC 2007). The Bureau of Land Management (BLM) *Programmatic Environmental Impact Statement* (BLM 2005) estimated that the permanent footprint of a facility is 5–10% of the site being developed, including turbines, roads, buildings, and transmission lines. Displacement effects, on the other hand, have much greater potential habitat impacts for species sensitive to human activities. Displacement is considered a behavioral avoidance of otherwise suitable habitat because of the presence of a wind facility and its infrastructure. If displacement effects are great enough then habitat fragmentation can occur. For the purposes of this discussion, fragmentation is considered the separation of a block of habitat for a particular species into two or more smaller blocks of habitat, so that the sum of the total value of habitat for the species is reduced.

Leddy et al. (1999) found that total breeding bird densities were lower in Conservation Reserve Program (CRP) fields with turbines compared to those without turbines in southwestern Minnesota. This reduced density was attributed to displacement of birds within 80 m of the turbine string (Leddy et al. 1999). Other studies (e.g., Johnson et al. 2000a, Erickson et al. 2004) suggest that the area of influence of wind turbines on grassland birds is within approximately 100 m of a turbine. Notwithstanding, there was no overall reduction in density within the larger area (the WRA) surveyed after the facility was in place (Johnson et al. 2000a, Erickson et al. 2004). Similar studies at the Stateline (Oregon-Washington) wind facility suggest a fairly small-scale impact of the wind facility on grassland nesting passerines, with a large portion of the impact related to direct loss of habitat from turbine pads and roads, and temporary disturbance of habitat due to construction areas (Erickson et al. 2004). Horned larks (*Eremophila alpestris*) appeared least affected, with some suggestion of displacement for grasshopper sparrows (*Ammodramus savannarum*), although sample sizes were limited. Shaffer and Johnson (2008) reported small-scale displacement of songbirds in a study of songbirds in North and South Dakota. This study is described in more detail as a case study in Chapter 5. Displacement of waterfowl and shorebirds from 100 to 600 m has been reported at wind facilities in Europe (Winkelman 1990, Pedersen and Poulsen 1991, Spaans et al. 1998, Fernley et al. 2006). A study conducted in England to assess displacement of wintering farmland birds by wind turbines located in an agricultural landscape found that only common (ring-necked) pheasants (*Phasianus colchicus*) appeared to avoided turbines. The other bird types and examined (including granivores, red-legged partridge [*Alectoris rufa*], Eurasian skylark [*Alauda arvensis*] and corvids) showed no displacement from wind turbines. In fact, Eurasian skylarks and corvids showed increased use of areas close to turbines, possibly due to increased food resources associated with disturbed areas (Devereux et al. 2008).

Most studies suggest that wind facilities have little impact on the nesting of birds (Howell and Noone 1992, Johnson et al. 2000b, 2003). The only report of avoidance of wind facilities by raptors occurred at Buffalo Ridge wind facility, Minnesota, where raptor nest density on 261 $km^2$ of land surrounding the facility was 5.94/100 $km^2$, yet no nests were present in the 32 $km^2$ facility, even though habitat was similar (Usgaard et al. 1997).

Prairie grouse and big game are likely candidates for displacement effects. Prairie grouse, which exhibit high site fidelity and require extensive grasslands, sagebrush, and open horizons (Giesen 1998, Fuhlendorf et al. 2002), may be especially vulnerable to wind energy development (Arnett et al. 2007b). Leks, the traditional courtship display grounds of greater sage-grouse (*Centrocercus urophasianus*), Gunnison's sage-grouse (*C. minimus*), sharp-tailed grouse (*Tympanuchus phasianellus*), lesser prairie-chicken (*T. pallidicinctus*), and greater prairie-chicken (*T. cupido*), are consistently located on elevated or flat grassland sites with few vertical obstructions (Flock 2002), terrain very often attractive to wind energy developers.

Several studies have demonstrated that prairie grouse strongly avoid certain anthropogenic features such as roads, buildings, powerlines, and oil and gas wells, resulting in sizable areas of habitat rendered less suitable (Braun et al. 2002, Holloran 2005, Pitman et al. 2005, Pruett et al. 2009, Robel et al. 2004). Much of the infrastructure associated with wind energy facilities, such as power lines and roads, are common to most forms of energy development and it is reasonable to assume that impacts would be similar. Nevertheless, there are substantial differences between wind energy facilities and most other forms of energy development, particularly related to human activity. While results of studies of other anthropogenic features suggest the potential exists for wind turbines to displace prairie grouse from occupied habitat, well-designed studies examining impacts of wind turbines themselves on prairie grouse are currently lacking. Ongoing telemetry research being conducted by Kansas State University to examine response of greater prairie-chickens to wind energy development in Kansas (McNew et al. 2009) and a similar study being conducted on greater sage-grouse response to wind energy development in Wyoming (Johnson et al. 2009a) will help to address this lack of knowledge. In addition to these ongoing telemetry studies, studies of lesser prairie chicken and sharp-tailed grouse response to wind turbines in Nebraska (Nebraska Game and Parks Commission [NGPC] 2009) and studies of greater prairie chicken response to wind turbines in Minnesota (Toepfer and Vodehnal 2009) have found that some prairie grouse on leks as well as nesting hens do not appear to avoid turbines on the sites studied. Greater prairie chicken lek surveys were conducted three years before and five years after construction of a wind energy facility at a site in the southern Flint Hills of Kansas (Johnson et al. 2009b). During the year immediately preceding construction of the project (2005), 10 leks were present on the project area, with 103 birds on all leks combined. By 2009, four years after construction, only one of these 10 leks remained active, with three birds on the lek. The 10 leks were located between 88 m to 1,470 m from the nearest turbine, with a mean distance of 587 m; eight of the ten leks were located within 0.8 km (0.5 mi) of the nearest turbine. Although this decline may be attributable to development of the wind energy facility, greater prairie chicken populations have declined significantly in the Flint Hills due to the practice of annual spring burning. During the same time frame that leks were monitored at the Elk River facility, the estimated average number of greater prairie chickens in the southern Flint Hills declined by 65 percent from 2003 to 2009. In Butler County, the estimated number of birds declined by 67 percent from 2003 to 2009 (Kansas Department of Wildlife and Parks, unpublished data). This regional decline is attributed primarily to the practice of annual spring burning and heavy cattle stocking rates, which remove nesting and brood-rearing cover for prairie chickens (Robbins et al. 2002). While not a true reference for this study area, this suggests that it is unlikely that the decline of prairie chickens on the Elk River site was due entirely to the presence of wind turbines (Johnson et al. 2009a).

The only study to have examined response of greater sage-grouse to wind energy development is being conducted at a wind energy facility in Carbon County, Wyoming (Johnson et al. 2010, Beck et al. 2011). Based on surveys at three leks, the mean number of males decreased from 43 in 2008, the year prior to construction, to 23 in 2010, two years post construction. Similar declines occurred on leks within a nearby reference area, where mean lek size decreased from 37 to 23 over this same time period, but the rate of decline appears to be slightly greater on the three leks in close proximity to wind turbines. Results of the telemetry study indicate that female sage-grouse used areas near wind turbines as late as two years after construction and no statistically significant differences in nest success and brood-rearing success for 2009 and 2010 occurred between the two sites. Notwithstanding, Johnson et al. (2010) and Beck et al. (2011) indicated that data from this study are preliminary and are not meant to form the basis for any conclusions regarding impacts of wind energy development on sage-grouse.

Outside of North America, the black grouse (*Lyrurus tetrix*), another grouse with a lek mating system, was found to be negatively affected by wind power development in Austria (Zeiler and Grünschachner-Berger 2009). The number of displaying males in the wind power development area increased from 23 to 41 during the 3-year period immediately prior to construction, but then declined to nine males four years after construction. While no reference data were reported, in addition to the decline in displaying males the remaining birds shifted their distribution away from the turbines. One lek located within 200 m of the nearest turbine declined from 12 birds one year prior to construction to no birds four years after construction.

Although the data collected on response of prairie grouse to wind-energy development indicate that prairie grouse may continue to use habitats near wind energy facilities, population declines in greater sage-grouse populations attributed to oil and gas production occurred four years post-construction (Naugle et al. 2009), and results of another study of oil and gas development suggested that there is a delay of 2–10 years before measurable effects on leks manifest themselves (Harju et al. 2010). Therefore, data spanning several grouse generations may be required to adequately assess impacts of wind energy development on prairie grouse.

Sawyer et al. (2006) determined that mule deer (*Odocoileus hemionus*) are displaced from suitable habitat by human activity related to the development and operation of gas wells in western Wyoming. While these studies suggest a potential displacement effect from the development of wind energy, the magnitude of the displacement effect from wind development may be different from other developments that use different technology and have more human activity associated with their operations. For example, a recent study regarding interactions of a transplanted elk (*Cervus elaphus*) population with an operating wind facility in Oklahoma found no evidence that turbines had a significant impact on elk use of the surrounding area (Walter et al. 2004). Similarly, Johnson et al. (2000b) found no effect on pronghorn use of the Phase I and

II Foote Creek Rim project in Wyoming. Virtually nothing is known about habitat-related impacts to other species of wildlife, including reptiles, amphibians, forest carnivores, and small mammals (Arnett et al. 2007b).

## ORGANIZATION OF THIS DOCUMENT

The information contained in this document provides a guide for conducting most wind energy/wildlife interaction studies. In addition, one of the goals of this document is to provide common terminology for those involved in conducting wind energy/wildlife interaction studies. Four commonly used terms in this document are metrics, methods, study design and protocol.

- *Metrics* are measurements, concepts, and relationships, such as miles per hour or, in the case of wind energy/wildlife interactions: animal utilization rate (e.g., birds seen/survey), mortality (e.g., carcasses/MW/year), risk (probability of an effect), and so on.
- *Methods* refer to observational or manipulative study techniques used to document animal location, numbers, use, behavior, and other associated parameters.
- *Study design*, which is part of methods, sets forth how, what, when, and where samples will be selected. The study design will need to be tailored to the specific project, whereas the metrics and other methods may not require modification from study to study.
- *Protocol* is a predefined plan of study that combines the metrics, methods and study design for a specific study.

For research to be found defensible, the metrics and methods should be scientifically credible and comply with the needs of legal and regulatory processes.

This document is organized into five chapters. Chapter 1 contains an introduction to the issues surrounding wind energy/wildlife interactions. The remaining chapters provide a detailed discussion of questions and the methods and metrics to address those questions, illustrated with case studies. Chapter 2 describes the first and very preliminary step in the process of screening potential sites for major wildlife issues that could influence the selection of a site or sites for development. Chapter 2 also describes the second step in the site selection process wherein sites remaining after preliminary screening process are evaluated using available site-specific information and one or more site visits. Chapter 3 describes detailed pre-construction studies that may be necessary for making a final decision to construct a facility and to design the facility to avoid, minimize and/or mitigate for unavoidable significant adverse impacts, and for making permit issuance decision or to satisfy an environmental review process. Chapter 3 also describes the process for designing and conducting the pre-construction portion of any studies that will involve pre- and post-construction components. Chapter 4 describes routine post-construction fatality studies and Chapter 5 describes a special case of studies that may be conducted at some facilities. These studies include the investigation of habitat impacts, evaluation of additional mitigation (risk reduction) measures potentially implemented at individual facilities and, when necessary, an evaluation of potential impacts to wildlife populations. The studies described in Chapter 5 are applied problem-solving efforts, address an acknowledged problem, and normally involve designs of impact assessment and/or manipulative studies including treatments and controls. Some of these studies may have a pre-construction component and these components are introduced in Chapter 3. Sections at the end of the document include *Literature Cited* and an *Index of Key Terms,* which provide definitions of terms used in this document.

Finally, the document includes three very important appendices. Appendix A contains Kunz et al. (2007a), a detailed description of the methods and metrics recommended for the study of nocturnally active birds and bats. Appendix B describes a potential framework for decision making that is specific to wildlife and wind turbine interactions, that is intended to provide a guide on how to ask the right questions that need to be addressed with respect to potential wildlife impacts (both positive and negative) when developing a wind energy project and how to choose which methods to use to address those questions. Appendix C provides a detailed discussion of statistical aspects of studies including the design of monitoring studies and more specific studies focusing on habitat impacts, manipulative experiments and population effects, including field and/or model-based studies.

# CHAPTER 2: PRELIMINARY SITE SCREENING AND SITE EVALUATION

## PRELIMINARY SCREENING OF SITES

Site screening will be necessary when a developer has identified a number of potential sites within a region, or is considering development in an area but has not identified a specific site to develop. Site screening typically occurs on a larger scale (e.g., physiographic region, county) using publicly available data, usually as a “desk-top” exercise with no site visit. Site screening is extremely important because it occurs at a point in the development process before significant resources have been committed to a particular site. A company screening potential sites will consider a great deal of data including but not limited to the wind resource, site availability, site development feasibility, existing infrastructure including roads and transmission, a market for the energy, land use, cultural resources, contaminants, wildlife and permitting requirements. While a developer will consider all of these issues when screening sites, the following discussion will consider only wildlife.

### Problem Formulation

Problem formulation is the first action at each stage in a risk and impact evaluation process. Because site screening typically is the first step in a multi-staged evaluation of wildlife issues in the development of a project, the problem formulation generated at this stage may influence all future stages of the evaluation process. The objective of problem formulation is to focus the risk analysis on the most relevant potential geographic and biological factors affecting wildlife risk. The first step in problem formulation for screening is to identify the scale (geographic extent) of the risk assessment. For example, should the evaluation be restricted to a small number of potential development sites, a single large wind resource area, multiple wind resource areas, some geo-political boundary (e.g., county), or a natural landscape unit (e.g., a watershed or range of a local population)? The scale of the evaluation will determine the resources that will be considered in the screening process.

The next step is the identification of wildlife species, groups of similar species, animal assemblages, and their habitat that are of concern because they are potentially at risk of impact from development. As with any type of energy development, the initial list of species will include all species and their habitat that potentially occur in the area of interest that are protected by federal and/or state law. This list will quickly be paired down to species protected as threatened or endangered under the federal ESA or state endangered species law, species protected by other federal laws including the Migratory Bird Treaty Act (MBTA, which includes most birds in North America, and the Bald and Golden Eagle Protection Act (BGEPA), other special status species, and habitat for these species. Special status species will normally include species being considered for protection under federal or state endangered species laws, species of recreational and/or commercial value (e.g., state game species), and species known to be susceptible to negative impacts from wind energy development (e.g., bats). This list of species of concern will determine, to a large extent, the questions that should be addressed during the preliminary screening process.

Problem formulation also should consider the potential types and causes of impacts to wildlife and their habitat resulting from wind energy development. The potential impacts include fatalities and habitat.

Fatalities directly attributable to a wind energy facility may include collisions with facility components such as turbine blades, turbine towers, overhead power lines, and fences; electrocutions (APLIC 2006; Arnett et al. 2007b) would also be considered direct fatalities. Fatalities could also result from predators attracted to the wind facility. For example, there is concern that perching opportunities for raptors within a facility might increase predation on ground nesting birds and displaying male prairie grouse. Non-collision fatalities have been reported for bats by Baerwald et al. (2008), wherein bat fatalities may be due to decompression injury.

Habitat impacts may be direct, indirect, short-term, and/or long-term. A direct impact to habitat refers to the physical elimination or degradation of habitat for a species as a result of the construction of roads, tower pads, substations, and construction areas. Roads, tower pads and substations are long-term, extending for the life of the project. Construction impacts are relatively short-term, if site restoration returns construction areas to pre-impact condition and care is taken to avoid the introduction of noxious weeds and disruption of the site's hydrology.

An indirect impact to habitat refers to the loss of use of otherwise suitable habitat for species. For example, some invertebrate species appear to avoid the edge (i.e., transition between habitats) because conditions near the edge (e.g., relative humidity, plant associations) may have been modified (NRC 2007). Other species, such as prairie grouse, may avoid an area due to disturbance even though the habitat is not substantially modified (e.g., Holloran 2005). Such displacement impact may be short-term if the disturbance is removed (e.g., construction) or the animals become habituated to the disturbance. However, if displacement results from modification of the habitat so that it becomes less suitable, the impact is expected to be of longer duration (NRC 2007). Likewise, if the effect is due to the presence of the facility and/or traffic within the facility, the impact is long-term (i.e., as the project is operational), unless habituation occurs.

While the species list is the primary driver of response to questions in evaluation, unique and/or protected landscapes and high value plant communities may also be included in the assessment. Such landscapes include those which are very limited in abundance or distribution, but that retain important environmental values.

When the scale, the resources of interest, and the potential impacts are identified, the next step in problem formulation is to identify the specific questions that will be addressed. The specific questions will vary with the regulatory environment, public interest, species, and landscape, but the questions listed in Table 2.1 will commonly be addressed for most sites.

**Methods and Metrics**

When relevant wildlife data are available, an effective approach to answering most site screening questions is the use of a computerized mapping tool, that is, some type of geographic information system (GIS). Most companies either have or have access to GIS technology. A complete description of GIS is beyond the scope of this resource document, but the reader is referred to the Guide to Geographic Information Systems (http://www.esri.com/industries/natural-resources/index.html) for detailed discussion of this technology. The mapping exercise may include overlay wind resource data from the NREL database (http://www.nrel.gov/wind/resource_assessment.html) or wind data generated by the company with base maps showing topography, existing infrastructure (e.g., roads and transmission), digital elevation, land cover, wetlands, protected areas and occupied wildlife ranges, particularly of state and federal protected species. (See Table 2.2 for examples.) This relatively simple approach is an exercise to determine whether, based on existing information, there are obvious places where wind development may result in significant adverse impacts to wildlife. Increasingly, state wildlife agencies and other sources of expertise are cooperating to provide on-line mapping tools that identify areas of concern regarding wind energy/wildlife interactions. Identifying and using such sources is a basic component of site-screening exercises.

**Table 2.1. Common questions that should be addressed during screening and assessment of a site, group of sites, or area of interest.**

| | |
|---|---|
| 1. | Are there large areas of intact habitat with the potential for fragmentation, with respect to species of concern with needs for large contiguous blocks of habitat? |
| 2. | Are there known critical areas for species of concern, including, but not limited to, roosting/resting areas, hibernacula, staging areas, winter ranges, breeding areas, nesting sites, brood-rearing areas, migration stopovers or corridors, or other areas of seasonal importance? |
| 3. | Does the landscape contain any areas of special designation, including, but not limited to, “area of scientific importance” or “of significant value”; federally-designated critical habitat; high-priority areas for non-government organizations; or other local, state, regional, federal, tribal, or international categorization that may preclude energy development? |
| 4. | Are there known threatened, endangered, federal “sensitive”, state-listed, or other special status species present on the proposed site? Is habitat (including designated critical habitat) present for these species, and how are these species likely to use the site? |
| 5. | Are there landscape features influencing the likelihood of encountering a rare species or high-quality natural community (e.g., rivers, lakes, wetlands, rim rocks, rare and uncommon plant communities) or protected landscapes and high value plant communities that retain important environmental values? |

Other more complicated site screening approaches have been proposed. In their review of the impacts of wind energy development on wildlife, the NRC (2007) of the National Academies of Science (NAS) recommended more than the simple ranking of relative importance of each area to wildlife when screening potential sites for development; rather, they recommended that pre-site selection evaluation also consider potential for impacts to occur if a wind facility is constructed on a particular site, and possible cumulative impacts, placed in the context of other sites being developed or proposed. One such approach was the PII screening process proposed by the United States Fish and Wildlife Service (USFWS) in their Interim Voluntary Guidelines (USFWS 2003). The guidelines described the PII as a two-step process:

1. Identify and evaluate reference sites within the general geographic area of Wind Resource Areas (WRA) being considered for development of a facility. Reference sites are areas where wind development would result in the maximum negative impact on wildlife, resulting in a high PII score (relative habitat value). Reference sites are used to determine the comparative risks of developing other potential sites.
2. Evaluate potential development sites to determine risk to wildlife, and rank sites against each other using the highest-ranking reference site as a standard. While high-ranking sites are generally less desirable for wind development, a high rank does not necessarily preclude development of a site, nor does a low rank automatically eliminate the need to conduct pre-development assessments of wildlife use and impact potential.

The reference area described for the PII emphasized the value of a highly diverse site, such as a wetland or a woodland complex within a grassland community, or a mosaic of grasslands and forests, rather than comparing similar areas. This approach increased the possibility that areas with a single important species, for example a grassland area with relatively few wildlife present but important habitat for a particular species of concern, might actually look like a good site for wind development when compared to a high-density wildlife habitat.

**Table 2.2. Typical sources for spatial data useful in screening.**

**Aerial Photos (Digital-Raster)**

Data Source: National Agriculture Imagery Program; ranging from 2005 to 2008. Some states have partial to total color infrared coverage. These are typically high quality maps, but there are times when the aerial coverage is poor or non-existent for a project area in more remote areas of the U.S.

Link: http://datagateway.nrcs.usda.gov/

**Breeding Bird Survey Routes (Digital-Vector)**

Data Source: USGS; based on surveys from 1966 to 1998. Any routes that were still considered active in 1998 are included in the available shape file. The information is useful, although it is somewhat dated.

**Digital Elevation Map (DEM) (Digital-Raster)**

Data Source: National Elevation Dataset 1999. Data quality high.

Link: http://ned.usgs.gov/

**Land Cover (Digital-Raster)**

Data Source: National Land Cover Dataset 2001; data ranging from 1999 to present. Data quality high and continuously updated.

Link: http://ned.usgs.gov/

**Topographic (Digital-Vector)**

Data Source: USGS 24K and 100K Quads. Data quality high.

Link: http://www.charttiff.com/

**National Wetlands Inventory (Digital-Vector)**

Data Source: USFWS National Wetlands Inventory (NWI); ranging from 1977 to present. Data are good when available. USFWS is in the process of creating all hard-copy NWI data to digital format but much of the U.S. is not yet complete, particularly in more arid/western states where digital coverage is spotty. The eastern half of the U.S. is pretty well covered.

Link: http://www.fws.gov/wetlands/

**State Natural Heritage Programs**

Data Source: A network of similar programs exists in states throughout North America. Each program in the network uses the same database methodology and software, and receives technical support from a coordinating organization known as NatureServe (http://www.natureserve.org). Most databases have the minimum requirement of ArcGIS 3.X or higher.

Examples:

*Link: http://www.dfg.ca.gov/biogeodata/cnddb/*
*Link: http://ndis.nrel.colostate.edu/*
*Link: http://dnr.state.il.us/conservation/naturalheritage/inhd.htm*
*Link: http://www.kansasgis.org/*
*Link: http://cugir.mannlib.cornell.edu/about.jsp*
*Link: http://www.dnr.state.oh.us/Home/Heritage/NaturalHeritage/tabid/2010/Default.aspx*
*Link: http://www.pdx.edu/pnwlamp/oregon-gap-analysis-program*
*Link: http://wdfw.wa.gov/hab/phspage.htm*
*Link: http://uwadmnweb.uwyo.edu/wyndd/*

The USFWS established a Federal Advisory Committee in 2008, the Wind Turbine Guidelines Advisory Committee (WTGAC), to provide public input and new specific recommendations to the USFWS that would be considered as they develop new guidelines. Recommendations from the committee were published in the spring of 2010 (WTGAC 2010) and final guidelines from the USFWS are expected to follow in late 2011 or early 2012.

The NRC (2007) report suggested an alternative paradigm for selecting reference areas wherein the reference area is similar to the area being proposed for development. The reference area or areas would be in similar landscape features with comparable wildlife communities where wind power facilities already exist. While this is offered as an approach to site screening it is more applicable to site characterization studies described in detail below.

Some evaluations have used a more comprehensive approach to screen potential development sites. Table 2.3 provides a detailed screening process using data on wildlife, landscape characteristics, environmental contaminants, and infrastructure manipulated through a spreadsheet (Dave Young, WEST, Inc., personal communication). The Comprehensive Environmental Issues Assessment (CEIA) tool included publicly available empirical data and subjective scoring to provide a CEIA Scorecard for each of a large number of potential development sites. The sites were then ranked according to their score and specific issues considered relevant to the difficulty of developing each site were identified.

As can be seen from the above discussion, the site screening process can range from a relatively subjective landscape-level mapping exercise where obvious deterrents to development are identified, to a very detailed and relatively time-consuming look at individual sites. The computerized mapping process can be accomplished by developers using in-house capability and is similar to the recommendations from the WTGAC (2010). This approach is most appropriate for the screening process envisioned in this framework.

### Decision Process

Regardless of which approach is used, the objective of the preliminary screening process is to identify sites that the developer wishes to consider further for development. The process for making a decision regarding which sites qualify for further consideration will likely be unique to each developer. However, preliminary site screening allows the developer to avoid sites with obvious serious environmental problems in favor of sites with little known environmental impact, or at least to identify sites that will be much more difficult to develop because of potential environmental problems.

## SITE EVALUATION

Site evaluation studies typically are conducted at one or more sites that meet most of the criteria for wind facility development (i.e., wind, transmission, and access, and lack of critical environmental flaws), although not all issues may have been worked out in detail. Potential environmental constraints are considered in more detail and additional site-specific data are necessary to determine if there is risk of substantial impacts to wildlife if the facility is constructed. Distinguishing features of site evaluation studies are that they focus on specific sites, use an in-depth evaluation of the available information about the sites, involve consultation with local experts, agencies and potentially the public, and normally include at least one visit to each prospective site(s).

**Table 2.3. Wildlife and natural resource elements of the Comprehensive Environmental Issues Assessment Tool.**

| Resource | Elements | Data Source | Data |
|---|---|---|---|
| Protected Lands | State lands (e.g., Game Range, state park), federal lands (e.g., National Park, Wilderness Area, Wildlife Refuge, ESA Critical Habitat), Wild and Scenic River, Native American Lands. | Maps. | Subjective score based on area. |
| Wetlands | Jurisdictional Wetlands and Ecological Wetlands. | Aerial photos, NWI, Topographic, USGS Land Use, and DEM Maps. | Relative ranking based on number of permits. |
| Natural Features Inventory | Landscape features influencing the likelihood of encountering a rare species or high-quality natural community (e.g., rivers, lakes, rim rocks, rare and uncommon plant communities). | Aerial photos, state and regional natural feature inventories (e.g., Michigan Natural Features Inventory (http://web4.msue.msu.edu/mnfi/explorer/index.cfm). | Area units/subjective score. |
| Federally-Listed Threatened and Endangered Species | Species protected under the federal ESA and similar state acts. | Maps and federal and state data bases (e.g., state National Heritage Program Natural Diversity Databases). | Subjective score based on proximity to potential habitat and occurrence areas. |
| Migratory Birds | Potential for area as migratory stopover, known migration corridor, proximity to Important Bird Areas (IBA). | Maps and federal and state data bases (e.g., state National Heritage Program Natural Diversity Databases), Hawk Watch sites, USGS Breeding Bird Survey routes. | Subjective score based on proximity to potential habitat and concentration areas. |
| Bats | Presence of a listed species, presence of hibernacula, potential for migratory bats. | Maps and federal and state data bases (e.g., state National Heritage Program Natural Diversity Databases). | Subjective score based on proximity to potential habitat and concentration areas. |
| Raptors | Presence of special status species, raptor nesting habitat or known nests, raptor migration corridors. | Maps and federal and state data bases (e.g., state National Heritage Program Natural Diversity Databases), Hawk Watch sites, USGS Breeding Bird Survey routes. | Subjective score based on proximity to potential habitat and concentration areas. |

At this stage in the evaluation, the site visit is a reconnaissance to subjectively evaluate the site's characteristics. The information gained from a site visit is useful in interpreting publicly-available information such as published studies, technical reports, databases, and information from agencies, both regulatory and conservation, local experts and local conservation organizations.

**Problem Formulation**

The objective of the site evaluation problem formulation is essentially identical to the process described for site screening, except that the focus is on one or more specific sites that remain under consideration for development. Some developers consider this step in the site selection process a "fatal-flaw" analysis. Compared to site screening, many of the issues are clearer in the problem formulation. For example, the scale (geographic extent) of the risk assessment is in reference to a specific site, or wind resource area, so the potential geographic extent of the potential impact of the project is more certain.

The next step is a review of the wildlife species, groups of similar species, animal assemblages and their habitat identified in the preliminary screening that are potentially at risk of impact from the development. Because the geographic extent of the potential development is more specific, the list of species will likely be shorter. The answers to the questions that should be developed in site evaluation are, as in screening, determined to a large extent by the species identified as occurring or potentially occurring on or nearby the site being evaluated and the presence of unique or protected landscapes and high-value plant communities.

The potential types and causes of impacts to wildlife and their habitat resulting from wind energy development are identical to screening, including fatalities directly attributable to a wind energy facility and direct and indirect habitat impacts. Additionally, with more certainty regarding the scale of the development and potentially better estimates for fatalities and habitat impacts, the significance of these impacts to wildlife populations and cumulative impacts with other planned or existing facilities at least can be subjectively evaluated.

As in screening, the specific questions will vary with the regulatory environment, public interest, species, and landscape, but the questions listed in Table 2.1 commonly will be addressed, this time for the specific sites using the more detailed information and information from the site visit. Conceivably, a decision could be made to develop a site at this stage of evaluation with no need for further investigation. For example, if a site is surrounded by or adjacent to existing facilities, and the data collected during the operation of these facilities indicate little adverse impact, a developer might pursue the necessary permits at the end of a site evaluation. Even when expanding an existing project, concerns for cumulative impacts may create the need for further study. If a decision is made to pursue permits, the level of detail included in site evaluation studies will be influenced by permitting requirements.

For a discussion of the various aspects of the permitting process regarding wind energy facilities, see *Permitting of Wind Energy Facilities: A Handbook* (NWCC 1998). Chapter 3 of the *Handbook* provides an overview of where, why, when, and how biological resources and bird and bat resources may be considered during the permitting process. Because of the evolving federal permitting process related to the BGEPA (50 CFR 22.26 and 22.27), the USFWS' Migratory Bird Website should be consulted for the most current information available to the public on these issues (www.fws.gov/migratorybirds/).

Permitting processes often have a defined time line, usually beginning with the formal filing of a permit application. Wildlife information normally will be collected during the pre-application period and may be simple and straightforward (e.g., site screening studies) or more complicated (e.g., baseline studies), depending on the wildlife resources and specific situation. It is valuable to understand the wildlife resource-related laws, standards, regulations, and ordinances of the project site areas. It is also useful to clarify early in the wind facility site evaluation process any project-specific and jurisdiction-specific legal and biological information that may be needed (NWCC 1998).

**Methods and Metrics**

Information-gathering at this stage can cover many variables and is intended to eliminate surprises late in the permitting process. By conducting an appropriate site assessment, the wind facility developer can decide whether to continue the development process at the sites of interest and potentially enter the permitting process or delay or abandon the development of one or more sites as a result of potential significant adverse impacts to wildlife.

*Sources of Existing Information*
<u>Local Expertise:</u> Seeking out local experts familiar with the site(s) being considered can save time as well as provide valuable information. Local experts can quickly identify potential bird and other biological concerns or issues at the site(s) under consideration. They may have an established working relationship with or knowledge of other persons or resources that can be utilized to provide valuable biological, regulatory, and legal information. Interviews should be documented in a written report. Local expertise can include the following:

- State fish and game agents/biologists
- Federal wildlife agents/biologists (e.g., USFWS, BLM, U.S. Forest Service [USFS], U.S. Geological Survey [USGS])
- University professors/graduate students
- Partners in Flight representatives
- National Audubon Society representatives
- State Chapters of the Nature Conservancy
- Hawk Migration Association of North America representatives
- Bird Observatory representatives
- Other knowledgeable parties

The following example illustrates the importance of contacting local experts. In the pre-permit evaluation of the Columbia Hills wind power site, the proponent for the site discovered that the State of Washington's wildlife agency had historical records of several bald eagle day roosts near the site. A reconnaissance level survey of the site also discovered a night roost used by a small number of eagles. This information was used in the final design of the wind facility and, had the project proceeded, would have resulted in the company eliminating at least one string of turbines that potentially placed birds using the roosts at risk (S. Steinhour, pers. comm.).

Literature Search: A literature search can provide valuable information about wildlife resources and their habitat in an area. Peer reviewed literature, environmental documents previously prepared for the site, nearby sites, or the general area, research reports (published and unpublished), natural history journals, and agency reports may be useful. Research results from other wind energy facilities with similar species and landscapes can be used in site evaluation to identify potential adverse impacts. As more wind energy/wildlife interactions study results become available, these resources will grow in their value for estimating impacts at new proposed developments. Many sources of literature will be gray literature, i.e., published and publicly available technical reports that have not been independently peer reviewed (e.g., agency, industry or stakeholder reports). Gray literature can provide useful information; however, the value of any literature should be determined by an experienced biologist with knowledge of the species of special interest in the area.

Natural Resource Database Search: Most federal, state, and local agency offices and many conservation organizations maintain databases of sensitive resources in the area of their jurisdiction or focus. Perhaps the most complete source of information about rare and endangered species and threatened ecosystems are the state natural heritage programs, originating through the effort of The Nature Conservancy (TNC) in the 1970s. The natural heritage programs form a network of similar programs throughout North America. Each program in the network uses the same database methodology and software, and receives technical support from a coordinating organization known as NatureServe (http://www.natureserve.org). State databases may be more comprehensive for specific local or regional resources (e.g., California Native Plant Society [http://www.cnps.org/], the Wyoming Game and Fish Department's Wildlife Observation System).

These databases can be valuable for determining whether sensitive wildlife species and other sensitive resources are known to use the potential site or vicinity. This information usually consists of known animal or plant locations, typically collected for other purposes. Consequently, a specific site may never have been inventoried for wildlife resources or a rare species existing on the site may not have yet been detected. Clearly, absence of evidence should not be considered evidence of absence and the result of database searches should be interpreted and used appropriately.

Some additional sources of information regarding sensitive species that should be searched include:

- National Audubon Society Christmas Bird counts
- Herbaria (e.g., Rocky Mountain Herbarium, New York Botanical Garden)
- Museums
- Breeding Bird Surveys summaries - available from the USGS Patuxent Wildlife Research Center (http://www.pwrc.usgs.gov/bbs/)
- State wildlife atlases/field guides
- State and federal endangered and threatened species lists and occurrence information
- Federal, state, and local resource agency offices
- State wildlife habitat relationship programs

- State Wildlife Action Plans or Conservation Strategies
- Ducks Unlimited
- National Audubon Society State and Federal Watch Lists

Finally, there are bibliographic databases that provide lists of publications and reports on a variety of wildlife issues including wind impacts (e.g., NREL's Wind-Wildlife Impacts Literature Database [WILD], which can be found at [http://www.nrel.gov/wind/wild.html](http://www.nrel.gov/wind/wild.html)).

Site Visit: A site visit is an important part of a site assessment. Notwithstanding, these site visits will be reconnaissance surveys, i.e., a qualitative assessment of the site and its characteristics, and will not involve designed quantitative studies. Reconnaissance surveys are on-site surveys used by a biologist to get a general feel for the site, topography, habitat for species of interest, potential use by those species, and presence of habitat for species of interest. This type of survey can provide valuable information for site characterization. Depending on the site and species known to occur there, reconnaissance studies combined with existing information discussed above may provide adequate information to estimate potential impacts sufficient to make siting decisions. In rare circumstances reconnaissance studies will detect potential environmental conflicts that may be sufficient to discourage development. In most situations, reconnaissance studies will identify information gaps and help focus more detailed studies of wildlife resources (i.e., baseline studies). Site visits also may provide an opportunity to evaluate the site in the context of the surrounding area, which may allow a general assessment of potential cumulative impacts to sensitive species or their habitats.

Vegetation Mapping and Wildlife Habitat Relationships: Each site should be visited by a trained and experienced biologist with specific knowledge of and experience detecting the wildlife species, particularly birds and bats, and other natural resources of the project site and vicinity. Plant and animal species, plant communities and other landscape features potentially providing habitat for species of interest (e.g., bat hibernacula, water bodies, cliff structures, large expanses of intact native plant associations) observed on the project site and vicinity should be documented. The vegetation associations should be identified and mapped at an appropriate scale (e.g. 1" = 500'). Wildlife habitat relationships are complex, but there is usually information available describing in general terms the habitat requirements of the species of interest and the presence of habitat for a particular species can be used to subjectively assess the likelihood the species will be present. Where available, species habitat preference and landscape and vegetation maps can be evaluated to develop lists of species that may utilize the site. Many states also have detailed information on seasonal ranges of important wildlife species, further supporting the likelihood that a species of interest may potentially occupy a site. See Morrison et al. (2006) for a review of the literature on wildlife-habitat relationships.

Sensitive species use (or likely use) is one determinant of a project's potential for significant adverse impact. If the value of the site for sensitive species is well known, more detailed studies may be needed to characterize the use (see Chapter 3). If a potential site has a high likelihood for biological conflicts, it may not be worth the time and cost of detailed site evaluation work (NWCC 1998). If the potential for species risk is likely to be low, then very little additional information may be needed. On rare occasions, there may be evidence of potential use of a site by species of interest because of existing data on similar areas although there is no record of use at the site being evaluated. In this situation, it may be desirable to complete a short-term on-site survey involving one or more additional site visits in attempt to verify use. For example, a site may be near an area frequented by a raptor species of concern during the spring migration but no evidence of use exists at the site being evaluated. In this case, one or more site visits during spring migration might help to determine presence or absence of the raptor.

*Short-Term On-Site Surveys and Monitoring*

Uses of the potential site may include such activities as breeding/nesting, roosting, migrating, wintering, migratory stopover, and foraging. Historical evidence and/or sign of significant use by species of interest and the presence of their habitat are early evidence that may lead to additional investigations. Short-term on-site surveys/monitoring refers to multiple reconnaissance visits to a site to document species use or some other needed information. When sufficient concern persists regarding the presence and use of the site by sensitive species or the numbers and types of species using the site, this short-term on-site survey may be needed for the developer to make the decision to proceed to the next level of evaluation (e.g., baseline studies). If a decision is made at this point to begin the permitting process, this type of study may also respond to permitting requirements for surveys less intensive than a baseline study but more involved than a single site visit.

Most reconnaissance surveys will occur during diurnal periods when the opportunity for actually seeing animals and their habitat is maximized. Nevertheless, many wildlife species of concern are active mostly during low light (crepuscular) periods at sunset and sunrise. For example, owls and bats are normally active at night. Birds and bats active during low light and at night may be resident, breeding, migrating, or wintering species. Concern about crepuscular or nocturnally-active species may warrant extending the reconnaissance surveys to cover these periods.

## DOCUMENTATION

It is important to document in writing how, what, when, and where all biological information was obtained throughout the site evaluation process. Written documentation ensures that credibility can be determined for both the biological information and how it was gathered. The integration of the site evaluation information into a written report that describes the resources and estimates potential impacts is valuable and often required.

### ADEQUACY OF THE DATA

At this stage of the site evaluation process, a decision should be made regarding whether the existing information is adequate and defensible for the permit application. Has adequate biological information been gathered? Adequate information is the amount and type of information needed to be in compliance with regulatory and environmental laws, ordinances, regulations, and standards of the jurisdiction(s) involved. Meeting the test of adequacy requires that the biological information (written report or raw data) is both sufficient and sufficiently clear to allow for reasonable estimates of wildlife impacts. Ensuring the smooth progress of a wind energy facility development project may also depend on avoiding impacts to wildlife and habitats that are not specifically protected under state or federal statutes and programs. It is advantageous to identify species that are of concern to local, state, or national conservation organizations. Addressing these concerns early and thoroughly in the site evaluation process may help a project withstand legal challenge by a third party or an agency. The types of information discussed in this chapter should be adequate to assist with making many project decisions.

## CASE STUDY – A SITE CHARACTERIZATION STUDY

The objective of the site characterization study (SCS) is to conduct an early screening of critical environmental aspects of a potential project, so that the project development team can determine early in the process whether potential environmental issues exist that warrant further detailed assessment. In particular, the SCS provides a platform for development of recommendations for pre-construction wildlife studies, as well as other detailed environmental studies (e.g., cultural resource surveys, wetland delineations, Phase I Environmental Site Assessments) that may be warranted prior to finalization of site development plans. The standard SCS is not intended to satisfy requirements imposed by permitting authorities or by laws/regulations. In some cases, however, the activities performed as part of the standard SCS may be used to assist in satisfying such requirements.

The activities comprising the SCS (see list below) are conducted for the entire area identified as the WRA and a two-mile buffer around the WRA. The WRA and the two-mile buffer are collectively considered the Evaluation Area.

The SCS includes various activities, some of which are not focused on wildlife. The wildlife activities are primarily focused on collection and review of publicly-available information:

- Evaluation of available mapping data to identify and characterize key land cover, characteristics and uses;
- Identification of federal, tribal and state lands, and any other areas owned or operated by public entities (e.g., local parks);
- Characterization of avian and bat species that could potentially be affected by the project;
- Evaluation of sensitive or protected biological resources that could potentially be affected by the project, including federally-listed and state-listed avian, bat, terrestrial, aquatic, and herbaceous species;
- Identification of designated protected, sensitive or special wildlife habitat (e.g., Important Bird Areas [IBAs; http://www.audubon.org/bird/iba);
- Identification of documented aquatic resources potentially subject to United States Army Corps of Engineers or State permitting, including wetlands, lakes, rivers, and streams;
- Evaluation of potential land-use related issues, including documented county/township restrictions (e.g., zoning, noise or visual restrictions, height limits, or setbacks), specially designated agricultural and conservation lands, and floodplains;
- Identification of potentially applicable State or local wind power siting or construction guidelines or protocols; and
- Preparation of an overview environmental permit matrix that summarizes the federal, state and local agencies with jurisdiction over environmental aspects of the project, and the specific permits/authorizations that likely will be required.

### Collection of Available Site Mapping Information

Site maps are prepared and incorporate Evaluation Area boundaries and other data. A GIS platform may be used to consolidate and display the various information collected and assessed as part of the SCS.

Typical mapping data include:

- Topographic contour data from the USGS National Elevation Dataset (NED) including datum, elevation unit, and projection;
- Political boundaries in the vicinity of and within the Site (including federal, state, county, township, and municipal);
- USGS 7.5-minute Topographic Maps;
- National Wetland Inventory (NWI) maps from the USFWS;
- USGS National Land Cover Data (NLCD) including 21 classes of land cover, percent tree canopy and percent urban imperviousness at 30 m resolution derived from Landsat imagery;
- State, federal and tribal land boundaries;
- Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (if available);
- Farm Service Agency Conservation Reserve Program maps (if available); and
- State-specific wind-wildlife maps.

### Evaluation of Land Cover, Characteristics and Uses

Based on the mapping data collected, the land cover and land use is characterized and described in graphical and tabular fashion. The general characteristics of the land are described in terms of landforms and ecoregions. Federal and state lands are identified and the intended purposes and/or constraints associated with the lands potentially impacted by the development considered. Additionally, other lands owned or operated by municipal entities (e.g., city parks) are identified, if possible based on available mapping data.

### Identification of Officially Designated Tribal Lands

On-line resources are used to identify and plot any officially designated tribal lands based on information provided in the United States Census Bureau's on-line GIS databases or other official sources (such as the individual tribe).

### Biological Resource Evaluation

The biological resources at the site are evaluated and characterized. Information is sought to help predict avian and bat use, the potential presence of federal and state listed species, common vegetation and unique landscape features.

**Pre-Field Evaluation**

The pre-field evaluation focuses on acquisition of existing information regarding biological resources, completion of a literature review including database queries for site-specific information, and evaluation of other relevant reports and literature to help evaluate potential biological concerns.

Sources of pre-field evaluation information typically include, but are not necessarily limited to, the following:

- Topographic maps;
- Aerial photographs;
- Published literature;
- Wildlife occurrence mapping;
- Wildlife and plant occurrence databases;
- Sensitive and protected species databases and maps;
- NWI (http://www.fws.gov/wetlands/) mapping;
- Land use/land cover mapping;
- Digital elevation mapping;
- Available literature from other nearby studies;
- The Nature Conservancy (TNC) mapping;
- Audubon IBA (http://www.audubon.org/bird/iba) mapping;
- Critical habitat mapping; and
- Breeding Bird Survey mapping and databases.

As appropriate for the region in which the Site is located, additional region-specific wildlife information resources (e.g., big game winter range) can also be included in the evaluation.

**Site Visit**

A qualified biologist with experience in evaluating wind power project sites and associated impacts conducts a visit to the site (typically one day in duration, with the potential to be longer for larger sites) to evaluate vegetation and other landscape features (e.g., topography, wetlands, streams, lakes) and potential for avian migratory pathways, and to look for raptor nests, prey populations, and other biological resources. The site visit is not intended to be an exhaustive biological survey, but is instead intended to provide a preliminary characterization of the ecological setting. Current wildlife habitat and land use practices are noted to help in determining the baseline against which potential impacts from the project could be evaluated. The vegetation and other landscape features are reviewed in order to assist in identifying wildlife resources with the potential to occur at the site. Species observed during the site visit are noted, with particular focus on any sensitive or protected resources.

## Agency Information Solicitation

State and Federal natural resource agencies are contacted to solicit information regarding their concerns about wildlife or plant resources in the site vicinity. At a minimum, the state natural resource agencies and the USFWS, primarily through the nearest Ecological Service Field Office, are contacted for information. Requests for information are included in the SCS Report, as well as copies of responses. Expressed agency concerns are discussed. Agency contact at this stage is simply solicitation of information and comment on the potential project. No agency meetings or long-term coordination for future studies are conducted for the purpose of the SCS.

## Identification of Wetlands and Waters of the United States

Publicly available mapping information is reviewed for the purpose of identifying wetlands and other Waters of the U.S. potentially present. If available, NWI maps are presented together with aerial photography maps. Additionally, land use/land cover data are reviewed to prepare an estimate of the amount of wetlands and water bodies present.

Additionally, if the associated information is available, floodplain designations are assessed and described. Conservation Reserve Program (CRP) information is solicited from the local USDA Farm Service Agency (FSA) office.

## Wind Power Guidelines and Permitting Requirements

An evaluation is conducted to identify and describe any potentially relevant draft or final wind energy facility siting or development guidelines. To the extent that they are available, copies of the guidelines are obtained and presented.

An overview environmental permit matrix is prepared. The permit matrix identifies federal, state and local agencies with potential jurisdiction over aspects of the project, the permits/authorizations for which each identified agency has jurisdiction, the “triggers” for each of the permits/authorizations, the general timing for permit/authorization approval, and any other relevant information concerning the permits/authorizations.

The overview environmental permit matrix may include some information regarding other (non-environmental) permit requirements (e.g., local building permit requirements) if this information happens to be obtained during the environmental permitting requirements information collection process; however, the overview environmental permit matrix is not intended to be all-inclusive of all regulatory requirements for the project.

In many cases, information regarding permitting requirements is best obtained via direct communication with government representatives.

## Reporting

Upon completion of data gathering, the site visit and analysis of information, a draft SCS Report is prepared and provided to the developer in electronic format. As a separate electronic file, an Environmental Management Plan (EMP) also is provided. The EMP provides summary-level information for the various topics of the SCS (e.g., Habitat, Wetlands, Threatened and Endangered [T&E] Species, etc.) together with recommendations for any associated further actions or studies.

### Next Steps

The SCS and the recommendations presented in the EMP are used to plan activities to address issues and recommendations outlined in the SCS, as well as general timing for completion of these activities.

## SUMMARY

Preliminary screening studies are landscape- or regional-scale screening processes allowing developers the opportunity to identify potentially significant environmental issues that can help in prioritizing sites for development. These studies rely on existing information, primarily in map form, and are generally less time-intensive and expensive than actual field studies. In most cases the data obtained for wildlife will be combined with other information (e.g., wind data, access, transmission) to complete the screening process. The screening process may include one or more potential sites, or no specific sites. The screening process is likely most useful for relatively large developers that have multiple sites in their development pipeline.

The next level of complexity, site assessment studies, occurs at sites that remain in the development pipeline following the screening. Site assessment studies address the same questions addressed during screening except that the questions are addressed for one or more specific sites. Site assessment studies are based on existing site-specific information and include one or more visits to each site.

## DECISION PROCESS

At the end of site assessment the developer, and potentially the permitting authority, must make a decision regarding whether to move forward with the project, either through the permitting process or to conduct additional and more complex studies. As with screening, the process for making a decision regarding which sites qualify for permitting or for further consideration will likely be unique to each developer. At the end of the site assessment, more site-specific information increases the developer confidence that a site is worth considering further and potentially that the permitting process may begin.

## CHAPTER 3: BASELINE STUDIES AND PREDICTIVE MODELS

## INTRODUCTION

The first level of effort focused on screening potential sites and the next level of effort focused on specific sites that made it through the screening process. If a developer decides as a result of the site assessment to proceed with a particular site, baseline studies provide quantitative data that (in conjunction with the literature) are useful both in providing estimates of impacts and risk, and in designing a project to avoid and/or minimize risk to wildlife. Baseline studies assess the existence of wildlife and their habitat prior to the construction of a project. While the study of wildlife will involve both diurnal and nocturnal studies, the main body of this document focuses primarily on diurnal studies. Appendix A specifically describes nocturnal methods and metrics. The general methods and metrics provided below and in the description of post-construction studies that follow are also applicable to studies of nocturnal wildlife species.

## PROBLEM FORMULATION

Problem formulation for baseline studies and predictive models (baseline studies) should include the following:

1. An evaluation of data gaps identified by site assessment studies in reference to the permitting for a project;
2. A pre-construction prediction of risk to wildlife and their habitat;
3. Data necessary to design a project to avoid or minimize risk;
4. Data useful in evaluating predictions of impact and risk through post-construction comparisons of estimated actual impacts to predicted impacts and risk; and,
5. Information useful in identifying the need for and in developing mitigation measures to offset unavoidable impacts.

The adequacy of mitigation measures to offset unavoidable impacts will vary with the regulatory environment, the magnitude of the impacts and the resources (i.e., wildlife and habitat) involved.

Baseline studies focus on wildlife species, groups of similar species, animal assemblages and their habitat that are potentially at risk of impact from the development. In most cases, this list will be a subset of the species of concern identified in the site assessment problem formulation, based on information generated during site assessment studies. Baseline studies also provide data needed to fill gaps identified during the site assessment stage.

While the specific questions will vary with the regulatory environment, public interest, species, and landscape, Table 2.1 lists the questions that commonly are addressed, this time for the specific sites using the more detailed information and information from the site visit made during the site assessment. Conceivably, a decision could be made to develop a site at this stage of evaluation with no need for further investigation. For example, if a site is surrounded by or adjacent to existing facilities, and the data collected during the operation of these facilities is publicly available and indicate little adverse impact, a developer might pursue the necessary permits at the end of a pre-construction site evaluation. Thus, the level of detail included in site evaluation studies may be influenced by permitting requirements.

Should the developer decide to proceed with the evaluation of a site, baseline studies will address those questions identified in screening and site assessment (Table 2.1) at a more quantitative level. Whereas earlier stages focus on the potential presence or absence of species of concern on the site, baseline studies attempt to fill in gaps in the existing data by quantifying empirically the distribution, relative abundance, behavior, and site use by these species. These data may also be used in a modeling exercise to estimate risk to these species from the proposed wind energy facility.

In addressing the Table 2.1 questions, developers should collect sufficient data to enable analysis that answers the following questions:

1. What are the potential risks of impacts of the proposed wind energy project to individuals and local populations? When necessary, due to the presence of rare and/or endangered species, assessment of risk also may include consideration of possible impacts to entire species and their habitats.
2. If significant impacts are predicted, especially to wildlife of interest, can these impacts be avoided, minimized, or mitigated?
3. Are there studies that should be initiated at this stage that would be continued following construction and during operation of the facility?

The final step in the problem formulation is the identification of the necessary site-specific protocols needed to address the above questions. The development of these protocols should follow the information contained in Appendix C of this document, in particular the statistical considerations addressing sampling and areas of inference (i.e., the scale of the study). These protocols also should consider how these data may be used in conjunction with post-construction studies. The protocols are best developed in collaboration with the federal and state wildlife agencies.

## ESTIMATING ABUNDANCE AND HABITAT USE

### Point-Count Surveys

Point counts are commonly used for surveying birds (Ralph et al. 1995; also see Appendix C) that are diurnally active as well as for some nocturnally active species (e.g., owls). Two types of point-count surveys may be conducted to assess bird use of wind resource areas (WRAs), depending on what the target species are. Long-duration large-plot surveys are typically conducted to estimate raptor use of a WRA. Plots usually have a 0.5-mile (800 m) radius viewshed, and survey periods at each plot typically range from 20 to 40 minutes (e.g., Hoover and Morrison 2005, Smallwood et al. 2009).

Large-plot surveys are conducted to assess estimated use of a WRA. This information can be used to predict potential impacts, and to design the wind energy facility to reduce or mitigate impacts by avoiding high-use areas. When habitat and topography are relatively uniform within a WRA, circular plots can be established using a systematic sampling design to sample the entire WRA (see Appendix C). If proposed turbine locations are known, the plots can be established to concentrate survey effort on these areas. Depending on the size of the proposed development, it is not necessary that every turbine location be included in a sample plot. However, the number of plots should be sufficient to ensure that the data collected are representative of the different topographic features, vegetation types, etc. of the entire WRA. If data will be used to assist with siting turbines – a priority, for example, where turbines will be located near rims, cliff edges, saddles or other topographic features that might concentrate raptor use – it may be desirable to have overlapping plots to ensure that all birds using the area will be recorded and their flight paths mapped so that all potential high-use areas can be mapped.

Although the surveys are designed to obtain data on raptors and other large birds such as waterfowl and waterbirds, all birds seen during each survey are recorded. Because it is often impractical to measure exact distances to birds, observations should be placed in distance bands, such as 0-25 m, 25-50, 50-100 m, etc. Temporary flagging and/or landmarks can be used to assist observers in distance estimation. Observations of birds beyond the specified radius can be recorded, but data collected on these birds should be analyzed separately from data collected on birds observed within the plot. The date, start, and end time of the observation period, plot number, species or best possible identification, number of individuals, sex and age class, distance from plot center when first observed, closest distance, height above ground, activity, and habitat are recorded for each observation.

Flight paths for all species of interest (e.g., raptors, sensitive species) typically are mapped and given observation numbers that correspond to the data sheet (e.g., Young et al. 2003b). USGS 1:24,000-scale topographic maps (or aerial photographs if available) attached to each data sheet showing the plot circle are useful for recording locations of observations as accurately as possible.

Bird behavior and habitat are recorded for each observation. Examples of behavior categories include perched, soaring, flapping, flushed, circle soaring, hovering, diving, or gliding. The approximate flight height at first observation and the approximate lowest and highest flight heights observed are typically recorded to within one- or five-meter intervals. Weather information recorded for each survey should include temperature, wind speed, wind direction, cloud cover and precipitation.

Plot surveys should be scheduled to cover all daylight hours, especially if raptors are of interest, and weather conditions. A schedule should be established prior to the field surveys to ensure that each station is surveyed approximately the same number of times each period of the day and to efficiently utilize personnel time by minimizing travel time between plots.

The number of raptors and other species seen during each point-count survey can be standardized to a unit area and unit time searched. For example, if 4 raptors are seen during a 20-minute period at a point with a viewing area of 2 $km^2$, these data are standardized to 4/2 = 2 raptors/$km^2$ in a 20-minute survey. This metric can then be compared to similar raptor use values collected at other WRAs, many of which also have raptor fatality data, to help predict the potential impact of the proposed facility on raptors (e.g., Figure 1.4).

The data can also be used to calculate a relative index to collision risk (R) for bird species observed in the project area using the following formula:

$$R = A*P_f*P_t$$

Where A = mean use for species *i* averaged across all surveys, $P_f$ = proportion of all observations of species *i* where activity was recorded as flying (an index to the approximate percentage of time species *i* spends flying during the daylight period), and $P_t$ = proportion of all flight-height observations of species *i* within the rotor-swept height (RSH). This index does not account for differences in behavior other than flight characteristics (i.e., flight heights and proportion of time spent flying).

Based on a regression analysis of raptor use and mortality for 13 new-generation wind energy facilities, where similar methods were used to estimate raptor use and mortality, there is a fairly significant correlation between pre-construction raptor use and post-construction mortality ($R^2$ = 66.4%; Figure 1.4). Therefore, raptor use data collected using the above techniques can be used to predict what actual raptor mortality might be, or at least whether it might be categorized as low, moderate, or high. One of the limitations of this analysis is that the raptor use estimates are diurnal studies where the mortality estimates include both diurnal and nocturnal raptors (e.g. owls).

Mapped flight paths obtained during the surveys are useful for siting facilities to avoid potential high raptor use areas. For example, the Foote Creek Rim WRA in Wyoming is located on a distinct table top mesa with steep slopes on the east and west sides. Mapped raptor flight paths indicated that raptor use was concentrated within 50 m of the rim edge (Johnson et al. 2000b). The developer agreed to not place any turbines within this area. Possibly as a result of this measure, raptor mortality at Foote Creek Rim was lower than predicted given the amount of use at the site (Young et al. 2001).

When passerines are a primary group of interest, point-count survey plots typically range from 50-100 m in radius and survey periods are usually 3-10 minutes in length. Unlike with raptors, there does not appear to be a strong correlation between pre-construction use by passerines and post-construction mortality. That said, Smallwood et al. (2009) found a correlation between monthly fatality rate and monthly rate of the number of birds/session crossing the turbine row based on a within-site comparison (monthly bird use associated with monthly bird mortality). Point-count surveys to estimate passerine use of WRAs are usually conducted to quantify passerine use of the WRA by habitat, determine the presence of sensitive species, and to provide a baseline for assessing displacement of passerines following development of the wind energy facility. Point-count surveys are especially appropriate in forested areas where most birds are detected by sound alone, but they are routinely used in all habitat types.

Point-count surveys can be used to estimate animal density using distance sampling methods (Buckland et al. 2001) when the distances to detected birds are recorded, allowing an estimate of the probability of detection. When the probability of detection is not estimated for point-count surveys, the data collected provide estimates of relative abundance rather than absolute density. Another method for estimating detection probabilities is to have two observers independently record birds at the same point (Forcey et al. 2006). Use of distance sampling and double counting add significant time (and cost) to the studies. For studies of WRAs with similar vegetation and topography, indices of relative abundance should be sufficient and comparable among surveys if the methods are standardized. However, comparisons among facilities with substantially different landscape characteristics must use estimates of density.

Passerine surveys typically are not used to estimate abundance, but rather to determine species composition, spatial distribution, and habitat use. Passerine surveys typically are conducted between a half hour before sunrise and four hours after sunrise. At each point, observers record all birds detected by sight or sound. Dettmers et al. (1999) examined data from point-count surveys conducted for 3, 5, 10 and 20 minutes. They concluded that for most species, except those with low detection rates, current recommendations for point count durations of 5 or 10 minutes are appropriate. Dettmers et al. (1999) also examined the number of visits. Models of habitat use based on a single visit did not perform as well as models based on repeated visits. However, there was little to no improvement when the number of visits was increased from 2 to 3. Therefore, when species composition and habitat use is the goal of a study, two visits to each point during the breeding season should be sufficient. However, if the objective of the surveys is to detect rare species, estimate abundance, or if it is expected that many species present may have low detection rates, then three or more surveys may be necessary (MacKenzie et al. 2006).

The USGS Breeding Bird Survey (BBS) is a standardized point-count survey along roads. Long-term data from the BBS are routinely used to estimate changes in bird abundance (Sauer et al. 2004). Each BBS route used by the USGS is 24.5 miles (39.2 km) long, with 50 points spaced at 0.5-mile intervals. The plot radius is 0.25 miles (400 m). All birds seen or heard at each point are tallied for a three-minute period. Breeding bird surveys are typically conducted in late May and June. Although BBS data normally are collected along a linear 24.5-mile road corridor, the points could be established in a grid throughout a WRA to obtain adequate coverage. While the BBS protocol is inadequate to estimate short-term abundance, BBS type surveys potentially could be used to establish breeding bird use of an extensive WRA area, when conducted in a double sampling plan (see Appendix C) with avian point counts, when using avian point counts over the entire area may be impractical.

Conducting point counts along roads is commonly done in WRAs for early risk assessments conducted before developers have signed leases with landowners and arranged for access to private property. A study conducted in shrub-steppe and grassland habitats in southwestern Idaho found that for most species, roadside surveys are not biased (Rotenberry and Knick 1995). They compared data from 200-m radius point counts centered on roads to similar point count data collected 400 m away from roads and found no differences ($P > 20$) in the number of individuals counted for all species but western meadowlark (*Sturna neglecta*). Meadowlarks were over-represented by roadside counts due to their tendency to perch on fences, which frequently occur along roads.

Data collected during passerine point-count surveys are similar to those collected for raptor surveys, and should include time, species, number, estimated distance from the observer, activity, habitat, flight direction, and estimated flight height. For data analysis, these flight heights are categorized to correspond to the height below, within, and above the space occupied by turbine blades. Weather data (temperature, wind speed and direction, cloud cover, precipitation) are also recorded each visit.

It is common for baseline estimates of bird use to be made using point count data collected for only one year, including one breeding season and a fall and spring migration. Using existing breeding bird survey data for the region containing an area proposed for development in combination with site-specific point count data can help address the question of whether data for one breeding season represent average, low or high use years for the proposed development area. Likewise, point count data for passerines during one or more migration season could be compared to NEXRAD data (Appendix A) to determine how use during baseline studies compares to a different estimate of relative abundance during migration.

### Transect Surveys

Some investigators prefer transect surveys over point counts for estimating distance in open habitats such as grasslands and shrub-steppe, where birds are easily observed (also see Appendix C). Transect locations should be established on maps to sample the area of interest.

Once established in the field, a global positioning system (GPS) unit can be used to record start and end points for use during future surveys. The transect start and end points should be permanently marked using a small fence post or piece of rebar; and, temporary flagging can be used to help keep observers oriented. For example, flags can be located every 200 - 300 m along the line, depending on the terrain, so that a flag is always visible in the distance. Flagging also can be periodically placed at varying distances from the line to assist with estimating distances. For example, different colored flags could be used to demarcate 25, 50, 100 and 150 m distances from the line. Observers should walk slowly along the line at a constant speed. If studies are conducted using transect surveys for the purpose of collecting pre-construction data for comparison with post-construction data, care should be taken to ensure that all observers follow a specific protocol (e.g., walk at approximately the same speed). If feasible, transects should be oriented such that observers don't walk towards the rising sun in the morning, as this makes viewing difficult.

When conducting transect surveys, an observer walks a pre-determined route and records all birds observed as well as the perpendicular distance of each bird from the line. Because it is often impractical to measure exact distances to birds, many studies use distance bands, such as 0-25 m, 25-50, 50-100 m, etc. However, use of a rangefinder may provide a more accurate and quicker method of obtaining actual distances (Ransom and Pinchak 2003). Several assumptions apply to use of line transect sampling: 1) birds on the line or within the first distance band are always detected; 2) distances are measured without error; 3) birds do not move in response to the observer; and 4) birds are not double counted (Morrison et al. 2006).

Transect surveys are useful for characterizing bird use of a WRA, particularly in the gradient analysis, and to survey for listed or other sensitive species. Data useful as the before component of BA and BACI (see Appendix C) displacement studies can also be obtained through use of transect surveys. In these cases the exact location of each bird detected is important for data analysis and the distance along the line also should be recorded so that bird locations can be mapped in relation to the proposed or existing turbine locations. As with point-count surveys, the distance to individual birds observed is necessary to estimate detection probabilities and density. Without density estimates, comparisons among areas is limited by the similarity of their respective landscapes. Transect survey data should be directly compared to other transect surveys rather than to point counts.

**Hawk Watch Surveys**

If a proposed WRA is in an area where migrating raptors may be of concern, methods similar to those used by hawk watch organizations may be appropriate to measure use. Hawk watch surveys follow a specific protocol that is a variation of the point-count survey. These surveys are conducted from a single or series of points, but the survey length can be up to several hours at the same location. There are currently over 1500 established Hawk Watch sites in North America (Lewis and Gould 2000), which provide valuable baseline data for comparison to similar data collected at WRAs. Historic hawk watch data can be requested from HawkCount (http://www.hawkcount.org/) or Hawk Watch International (http://www.hawkwatch.org/home/).

Hawk watch surveys typically are conducted on prominent ridges or coastlines where raptor migrations are likely concentrated. Migrating birds are detected using the naked eye, binoculars, or even spotting scopes. Usually several people ("spotters") are used to help detect migrating raptors. For surveys conducted during the migration season, typically only birds moving in a southerly direction (fall) or northerly direction (spring) are defined as migrants. Birds are officially counted only after they pass by the observer. Fall counts may start as early as August and can continue through December, while spring counts typically begin in February and continue into early June, depending on location. If obtaining data throughout the entire raptor migration period is not warranted, the survey period can be shortened to 30 or 60 days to target the peak of raptor migration activity. Counts do not have to be continuous during these periods, but count intervals should be frequent enough (2 or more days per week) to provide an adequate assessment of raptor migration activity. The number of count days per week required for sufficient monitoring should be evaluated on a site- and species-specific basis (Lewis and Gould 2000). Because of high year-to-year variability in the numbers of migrants tallied at most sites, more than one year of data may be required to adequately evaluate raptor migration rates at a WRA. Alternatively, Hawk Watch data collected at existing points by others may be compared to point counts during the same time period to evaluate the point count data with respect to year-to-year variation.

**Territory/Spot Mapping**

Territory mapping is used in instances where more specific information on impacts to breeding birds is required.  It is not a subset of point count or transect surveys. Because breeding birds are territorial, the breeding territory of an individual can be delineated by making repeated observations and mapping these locations. Territory mapping is often used to determine the number of breeding pairs occurring in an area. Territory mapping is conducted by making repeated visits, often as many as 10 visits, to a study area during the breeding season (Bibby et al. 1992). During each visit, all birds detected by sight or sound are mapped on a large-scale map of the study area. To assist with accurately locating sightings, maps should be made prior to the study depicting habitat types, as well as individual objects such as trees, shrubs, roads, etc. Colored survey stakes can be placed on a grid within the survey area to aid in accurately mapping bird locations. Compasses and rangefinders also can be used to assist in accurately locating birds (Collister and Wilson 2007). The availability of GPS units has simplified the recording and management of spot mapping data, which has substantially reduced (but not entirely eliminated) the need for marking areas with stakes and flags. Data on bird locations collected in the field by GPS units can then be downloaded and mapped on GIS-generated images (e.g., from satellite imagery or aerial photos).

Mapped locations for each species are combined to depict the number of breeding territories in the study area. Information to record for each sighting should include species, sex and age, behavior, and habitat. If working on different plot sizes, the amount of time on each plot should be proportional to plot size (Kirsch et al. 2007). Territories can be delineated and mapped using the minimum convex polygon method. Data can be expressed as the number of territories per unit area (Weakland and Wood 2005). Because territory mapping is very time-consuming, it is best used for small study areas. Shaffer and Johnson (2008) used a variation of the spot-mapping technique to map bird locations within grassland plots around turbines in North and South Dakota for a study to examine displacement of grassland birds.

**Raptor Nest Surveys**

Raptor nest surveys are conducted to quantify abundance and species composition of breeding raptors in the study area, as well as to map raptor nest locations so that wind energy facilities can be sited to avoid impacts to nesting raptors. When the project is located on federal land, federal agencies such as the BLM and USFS typically have no surface occupancy (NSO) buffers around nests, where turbines or other permanent facilities are not allowed, as well as timing restrictions during the nesting season when construction activities are not allowed to occur. Therefore, it is important to map raptor nest locations so that their locations can be taken into consideration when developing turbine layouts as well as in planning the timing of construction activities.

Depending on several factors, including objectives for the study, the size of the area, topography, and abundance of raptor nesting substrates such as trees, cliffs, rocky outcrops and powerlines, aerial and/or ground-based surveys should be conducted. Aerial surveys are usually advised when the project area is too large to be adequately covered from the ground or is difficult to access, or when raptor nesting substrates are abundant or hard to examine from the ground (e.g., long areas of cliff face). Surveys should include the development area and an appropriate buffer, the magnitude of which will normally be a function of study objectives and discussion with the appropriate agencies. Ground-based surveys can be conducted by driving areas with good road access or by walking in areas where no roads are present. Binoculars and spotting scopes are used to survey areas of likely nesting habitat.

Occupancy determination is the most important goal for the raptor nest searches (Pagel et al. 2010). A nesting territory is an area that contains, or historically contained, one or more nests within the home range of a mated pair (Pagel et al. 2010). Steenhof and Newton (2007) further define territory as a confined locality where nests are found, usually in successive years, and where no more than one pair is known to have bred at one time (Steenhof and Newton 2007). Occupancy should be determined for all historical nesting territories and ones identified from the initial survey. Nesting territories and inventoried habitats should be designated as: (1) *Unoccupied* - territory is unoccupied during at least two complete aerial surveys spaced 30 days apart; or (2) *Occupied* - an adult, eggs, or young, freshly molted feathers or plucked down, or current years' whitewash are present (Pagel et al. 2010). Data collected during the inventory of territories located within the survey area should follow the inventory standards of Pagel et al. (2010) which include documenting the status of each territory as: Unknown; Vacant; Occupied - 1 bird; Occupied - 2 birds, laying or non-laying. This survey should occur following the nesting chronology of raptor of interest.

Aerial raptor nest surveys are usually conducted from helicopters due to the need for maneuverability and ability for slow flight speeds. However, surveys also can be conducted from fixed-wing aircraft (e.g., Ayers and Anderson 1999). Aerial surveys are only capable of detecting nests visible from the air, such as those of eagles, buteos, and certain owls, such as great horned owl (*Bubo virginianus*). These surveys are not appropriate for detecting ground nesting species (e.g., northern harrier, burrowing owl) or cavity nesters (e.g., American kestrel [*Falco sparverius*]). Nests are located by searching suitable nesting habitat, such as stands of trees, rocky areas, cliffs and certain man-made structures such as utility lines and windmills. The helicopter can be flown at an altitude of approximately 76 m (250 feet) and lower during surveys. When a nest is observed, the helicopter should be moved to a position where the observer can determine if the nest is occupied and the species occupying the nest. Efforts should be made to minimize disturbance to breeding raptors, including keeping the helicopter a maximum distance from the nest at which the species can be determined. Those distances vary depending upon nest location and wind conditions. Locations of inactive nests also should be recorded, as nests may be occupied during future years. The locations of all nests should be marked using a GPS, mapped on field maps, and given a unique identification number. Surveys should be conducted after most raptors have begun nesting but prior to deciduous tree leaf-out so that nests are most visible. Depending on the species nesting in the area, one survey may not be adequate to detect all nesting species. For example, in the western United States, great horned owls and eagles typically nest much earlier than Swainson's hawks (*Buteo swainsoni*), and surveys conducted during the appropriate time to detect eagles would not detect Swainson's hawks.

Data to be collected for each nest observed should include status (active, inactive), condition (e.g., good, fair, poor), species, stage (eggs, young in nest), and substrate (e.g., deciduous tree, cliff).

Certain precautions should be taken when conducting aerial surveys. Any residential areas within the survey area should not be surveyed. Rural residential areas should only be surveyed if the helicopter or plane can be kept at a minimum distance of ¼ mile from occupied residences. The helicopter or plane should be kept at an altitude of approximately 152 m (500 feet) while traveling between survey and staging areas to minimize effects on residents. Attempts should be made to minimize disturbance to horses, cattle, pets and other livestock. The helicopter or plane should be kept approximately 400 m (¼ mile) from livestock and pets, but greater distances may be warranted if livestock or pets appear disturbed.

Several studies have found that aerial surveys routinely miss nests. For example, during fixed-wing aerial surveys to estimate ferruginous hawk (*Buteo regalis*) populations in Wyoming, observers detected 23.7%-36.5% of known nests (Ayers and Anderson 1999). Many ferruginous hawks nest on the ground or on rock outcrops, and nests of this species are likely harder to detect than nests located in deciduous trees. However, aerial surveys should be followed by ground surveys, especially in areas within NSO zones or buffers associated with timing restrictions.

A comprehensive survey would include the identification of all occupied and unoccupied raptor nests. Basic nest use should be recorded and include: (1) *Unoccupied* - a nest with no evidence of recent use, or attendance by adult birds of prey; (2) *Occupied* - a nest site, or series of supernumerary nests within a 1-km radius, that revealed recent refurbishing (greenery, recent egg cup), or is represented by one or more adults on, or immediately adjacent to, nest structure(s); (3) *Successful* - a nest that fledged at least one young; (4) *Unsuccessful* - a nest known to be active but displaying addled/infertile eggs, a destroyed clutch, dead young, or empty at a period when dependent young should be present; and, (5) the number of chicks fledged (Steenhof and Kochert 1982). This type of survey will require visits throughout the nesting chronology of the raptor of interest. Often two to three surveys of each nest are required to determine nest timing so that future visits can be timed to coincide with fledging.

**Prairie Grouse Lek Surveys**

Much concern has recently been expressed regarding the potential impacts of wind energy facilities on prairie grouse species, which include the greater sage-grouse, greater and lesser prairie chickens, and sharp-tailed grouse. It is currently unknown how prairie grouse, which are accustomed to a relatively low vegetation canopy, would respond to numerous wind turbines hundreds of feet taller than the surrounding landscape. Some scientists speculate that such a skyline may displace prairie grouse hundreds of meters or even kilometers from their normal range (Manes et al. 2002, NWCC 2004, USFWS 2003). If birds are displaced, it is unknown whether, in time, local populations may become acclimated to elevated structures and return to the area, although Robel et al. (2004) did not detect habituation by the greater prairie chicken to other forms of development. The USFWS argues that because prairie grouse evolved in habitats with little vertical structure, placement of tall man-made structures, such as wind turbines, in occupied prairie grouse habitat may result in a decrease in habitat suitability (USFWS 2004).

If prairie grouse are potentially present on a WRA, historical data on lek locations and activity can be reviewed and active lek locations documented and mapped by conducting field surveys when males are attending leks. Depending upon the size of the study area, surveys can either be aerial or ground-based. When conducting aerial surveys, either fixed-wing or helicopters can be used. Parallel transects designed to provide full coverage of the project area and appropriate buffers should be flown. Prior to conducting the surveys, known locations of historic and existing leks should be obtained from appropriate federal and state natural resource agencies. All mapped leks should be flown to check for occupancy. To search for additional leks in the survey area, transects oriented north-south and separated by approximately one kilometer should be flown. Transects should be flown at a height of approximately 100-150 meters. Flights should take place from one-half hour before to one hour after sunrise, and should only occur during calm, clear mornings. Two observers in addition to the pilot should be used to conduct the surveys. GPS coordinates and approximate number of grouse observed should be recorded for all leks located.

Because accurate counts of birds on leks cannot be obtained from the air, follow-up ground surveys should be conducted of all identified leks. Each active lek located during aerial surveys and all known historic lek locations should be visited at least three times from the ground to count the number of grouse using the lek. Counts on each lek should be separated by 7-10 days. Counts should be conducted for a 15-30 minute period in the early morning (½ hour before to one hour after sunrise). Ground surveys should only be conducted when winds are light and there is no precipitation. Data collected should include maximum number of males, females, and unknown gender birds observed, time, date, habitat, weather information and behavioral observations. A GPS should be used to record the approximate lek center and perimeter of each lek in the survey area. Although accurate counts of sage-grouse can typically be achieved without flushing the birds, prairie-chickens and sharp-tailed grouse may have to be flushed to obtain accurate counts.

When conducting surveys from the ground, observers should stop every 800 m (0.5 mile) along roads (if access is suitable) or along transects spaced one mile apart, and listen for displaying males. Binoculars also should be used to scan suitable habitat for birds on leks. Three surveys should be spaced at least seven days apart.

If post-construction impact studies are planned, additional pre-construction data will be required. Relating changes in lek activity after a project is constructed to the effect of a wind facility will require that surveys of one or more reference leks and the impacted lek be completed both before and after the project (see Appendix C). Because grouse exhibit such high site fidelity, an effect of facility development on them may take several years to detect, and may result in fewer and fewer displaying males over a number of years post-construction. At a minimum, lek surveys and male counts should be conducted annually for the first five years post-construction. If an impact occurs and there is interest in determining if recovery follows, surveys should be continued every 5th year thereafter, for the life of the project.

**Radio Telemetry**

Radio transmitters provide cost-effective and convenient means of remotely monitoring the movements, resource selection, behavior, and demographics of animals (Millspaugh and Marzluff 2001). Radio tracking wildlife began nearly 50 years ago and has advanced tremendously in the last decade or so (Kenward 2001). While not typically a pre-construction study method, radio telemetry studies can be conducted to obtain data on how birds and other wildlife use a WRA (see also Appendix C). Study objectives may include obtaining pre-construction data for site planning and for post-construction comparisons to assess displacement impacts as well as effects on demographic parameters such as survival and reproduction. In some cases, such as when dealing with threatened or endangered species, telemetry also can be used to determine how a WRA is used by a particular species of interest. The resulting data can be used to site facilities to avoid or minimize impacts.

Radio telemetry involves capturing individuals and placing a transmitter on them so that their locations and movements can be tracked over time. Two types of transmitters are available, including very high frequency (VHF) transmitters and GPS transmitters. When using VHF transmitters, researchers have to obtain locations either from foot, vehicle or airplane. The number of locations depends on the amount of time spent tracking individual animals. GPS transmitters use satellites to obtain animal locations, and these GPS transmitters can collect an almost unlimited number of animal locations per day at high accuracy (i.e., within a few meters). There are advantages and disadvantages associated with using VHF and GPS transmitters. The VHF transmitters are much cheaper. For example, a VHF necklace type transmitter typically used on upland game birds costs approximately $150-$200, versus around $4,000 for a single GPS transmitter. Additionally, GPS units weigh substantially more than an equivalent VHF unit and thus cannot be used on smaller species. There are also costs associated with satellite time for storing data. Substantially more animals can be tracked using VHF transmitters for the same price, but the labor involved is much higher for tracking animals after they have been collared. Determining which type of transmitters to use will depend on study objectives, sample size considerations, and available budgets. Regardless of the method used, telemetry studies are expensive and usually are not warranted unless there is substantial concern over potential impacts to certain species.

Because of the expense, there has been few telemetry studies conducted for wind energy facility risk assessments. As an example of how telemetry data could be used to assess risk, the Washington Department of Fish and Wildlife (WDFW) recently used GPS telemetry to monitor golden eagle and other raptor use of a proposed wind energy facility in Klickitat County, Washington. GPS transmitters were attached to a local nesting pair of golden eagles. Locations were recorded once an hour and were accurate to within 15 m. Core use areas were determined using a 95% kernel home range estimate, and these maps were overlaid onto proposed turbine locations to determine the degree of overlap and assess potential risk to the eagle pair (Jim Watson, WDFW, unpublished data). Granger Hunt (Hunt 2002) used VHF telemetry on golden eagles at the APWRA over a 4-year period to determine the demographic effect of the relative high number of annual fatalities within the WRA.

Telemetry also can be used on relatively small animals such as bats (e.g., Johnson et al. 2010; Watrous et al. 2006; Menzel et al. 2005). For example, the miniaturization of radio-transmitters has dramatically improved our knowledge of use of roost sites, foraging areas, and habitat types by bats in recent years (Hayes 2003, Brigham 2007). The GPS transmitters and receivers used with Argos satellites, however, are currently too large to be used on passerine birds and small bats (Aldridge and Brigham 1988). Kunz et al. (2007a; Appendix A) discuss radio tracking as a tool for studying nocturnal wildlife at proposed and operating wind facilities. Others have reviewed radio tracking methods extensively and those designing radio tracking studies will find White and Garrott (1990) and Millspaugh and Marzluff (2001) to be important references.

New global positioning system (GPS) technology such as the global system for mobile communications (GSM) is still in its infancy, and recent statistical advancements in estimation of home ranges and movement events (e.g., Sawyer et al. 2009a) have yet to be applied to most GPS data. Future telemetry studies should take advantage of technological advancements, which will improve our understanding of wildlife movements and habitat use in relation to wind energy projects.

### Surveys for Other Wildlife Species

It is uncommon for pre-construction studies at wind energy facilities to be concerned with species other than birds or bats, and consequently we have devoted little attention to method and metrics for the study of other species. Large mammals are the most common species for which concern is expressed when wind projects are being evaluated. At western wind facilities located in native range, the typical species of concern are elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and pronghorn (*Antilocapra americana*). In the Midwest and eastern United States and Canada, white-tailed deer (*Odocoileus virginianus*) and black bear (*Ursus americanus*) may be impacted by development of wind energy (Arnett et al. 2007b). Direct loss of habitat for large mammals resulting from wind development has been documented in several states, although these losses generally encompassed habitat in adequate supply and, to date, have not been considered significant (Arnett et al. 2007b). At the Foote Creek Rim facility in Wyoming, pronghorn observed during raptor use surveys were recorded year-round for two years before and two years after construction (Johnson et al. 2000b) and results indicated no reduction in use of the affected area. A recent study regarding interactions of a transplanted elk population with an operating wind facility found no evidence that turbines had significant impact on elk use of the surrounding area (Walter et al. 2004). There has been concern expressed that development of wind power in the northeast United States on forested ridge tops, in stands of mast-producing hardwoods, and in wetlands will have a negative impact on black bears. Large mammals may avoid wind facilities to some extent, depending on the level of human activity. These impacts could be negative and perhaps biologically significant if facilities are placed in the wrong locations, particularly if the affected area is considered a critical resource whose loss would limit the populations (Arnett et al. 2007b).

The distribution and relative abundance of diurnally active animals can generally be determined with systematic observational surveys of the area of interest using point count or line-transect surveys as described above for birds and in Appendix C, looking for animals, their sign, or both. Protocols and survey methods for reptiles and amphibians are well established (e.g., Corn and Bury 1990, Hobbs et al. 1994, Olson et al. 1997, Ryan et al. 2002, Bailey et al. 2004, Graeter et al. 2008), and specific protocols for specific sites should be determined and agreed upon with state and federal agencies. If absolute abundance is desired then line-transect methods using distance or mark-recapture methods as described in Morrison et al. (2006; also see Appendix C) will be necessary. “Sign” of animal activity, such as fecal droppings and footprints, is typically used as an indication of use rather than abundance. Because sign may be used as an indicator of relative abundance for some species, one must be aware of the potential for differential use of different types of habitat. For example, mammals often leave more feces near feeding, bedding or hiding cover and less during movements. Alternatively, prairie dog relative abundance is frequently based on the number of active burrows in a given unit of study. A burrow typically is determined to be active based on the presence of a prairie dog or sign at the burrow entrance. For a detailed description of methods and metrics for other species the reader is referred to The Wildlife Society’s Wildlife Techniques Manual (TWS 2005).

Estimation of distribution and relative abundance for nocturnally active species is more challenging as direct observation is difficult. The methods and metrics for nocturnal surveys of birds and bats (Kunz et al. 2007a) are contained in Appendix A of this document. For terrestrial mammals, surveys of indirect measures of animal abundance, such as track counts, are often required.

**Habitat (Habitat Mapping)**

Pre-construction baseline and modeling studies should include an estimate of the habitat available for species of interest. Habitat estimates typically are based on a map of various resources for a specific study that are considered important habitat features (e.g., vegetation, topography). Potential habitat maps are created using identical methods described for mapping at the landscape scale for screening, except that habitat is mapped for a specific site, for a specific species and typically in more detail. Habitat mapping should take advantage of existing mapping conventions used in the state where the project is being considered for development. The following is an example of the methods for detailed habitat mapping.

*Identification and Description of Habitats in the Study Area – Case Study*
The following is a case study from a project in Eastern Oregon (Oregon Department of Energy [ODOE] 2007) using a classification developed by the Oregon Department of Fish and Wildlife (ODFW 2003). The case study illustrates general land cover mapping and more detailed descriptions and quantification of landscape condition and value. The Oregon example uses the term "habitat category" to describe different landscape forms ODFW felt provided habitat for important species. These resulting classifications serve as the basis for determining the level of mitigation for the direct permanent impacts to habitat. These general categories are:

***Category 1:*** Irreplaceable, essential habitat for a fish or wildlife species, population, or for a unique assemblage of species; and, that is limited on either a physiographic province or site-specific basis, depending on the individual species, population, area requirements or unique assemblage.

***Category 2:*** Essential habitat for wildlife species, population, or unique assemblage of species that is limited either on a physiographic province or site-specific basis depending on the individual species, population, or unique assemblage.

***Category 3:*** Essential habitat for fish and wildlife, or important habitat for fish and wildlife that is limited either on a physiographic province or site-specific basis, depending on the individual species or population.

***Category 4:*** Important habitat for fish and wildlife species.

***Category 5:*** Habitat for fish and wildlife having high potential to become either essential or important habitat.

***Category 6:*** Habitat that has low potential to become essential or important habitat for fish and wildlife.

The objectives of habitat mapping surveys are to identify the vegetation types (plant associations) and other landscape features (e.g., topography) that provide potential habitat for species of interest and that may be directly impacted by development of the study area. Of particular interest is the estimation of habitat potentially suitable for federal or state listed and sensitive species, including rare plants, on the study area.

In this case study, surveyors produced a map of vegetation associations and other landscape features that could be used to identify potential habitat for species of interest. Valuable information resources included recent aerial photography, field surveys and existing vegetation maps. A vegetation map was developed based on general vegetation types (e.g., grassland and forest) and land-use (e.g. cultivated areas, developed areas, bodies of water). Common land unit (CLU) boundaries and CRP enrollment data were mapped and ground-truthed to distinguish native habitats from CRP grasslands.

This general vegetation map provided some indication of the amount and location of potential habitat for some species, both plant and animal. This information was used to predict potential impacts, delineate the areas to be sampled for presence/absence of sensitive wildlife or plant species, and to aid in estimating habitat impacts for mitigation purposes. The potential impacts were determined by estimating the amount of each vegetation and habitat category permanently impacted by the facility by overlaying the footprint of the project onto the habitat layers. In addition, the amount of temporary impacted areas such as construction laydown areas, underground collection facilities, etc. were also calculated by habitat category. The mapped boundaries of each vegetation and land use type were digitized using ArcView™. The habitat mapping surveys covered the area proposed for development, and included a buffer around the impact area. The size of the impact zone will vary by topography, vegetation, and wildlife species of concern. In this study, habitat categories for each species of interest found within the study area were identified and mapped within the potential impact zone (the analysis area), or 228 m (750 ft) from project facilities (Table 3.1, Figure 3.1). The analysis area included the turbine development corridor, a 228 m buffer from the edge of development corridors, a 305 m (1,000-ft) buffer from all other linear components (e.g., underground and overhead transmission lines and road corridors), and the edges of the substation and laydown areas.

*Mapping Results and Impact Acreage Calculations*
In this example at a landscape (i.e., broad spatial extent) scale, the study area is dominated by agriculture; grassland and sagebrush/shrub-steppe, and CRP, with riparian cover types present in drainages and deeper canyons. Land cover in the analysis area consisted of non-irrigated cropland (83.4%), sagebrush/shrub-steppe and grassland (10.5%), CRP (3.4%), and developed areas (1.5%). All other cover types collectively comprised less than 5% of the study area (Table 3.2, Figure 3.2). Note that if specific surveys are not performed, general land cover information may also be obtained from the National Land Cover Database (USGS NLCD 2001) to determine land use/land cover in the study area.

Table 3.3 contains a description of the project area classified into the Oregon “habitat” categories. For the purposes of this example, Category 1 habitat in the project area includes trees with active raptor nests, while Category 2 habitat includes intact high-quality mature and relatively weed-free large shrub-steppe patches that provide potentially suitable habitat for sensitive grassland bird species like the grasshopper sparrow. Conservation Reserve Program habitat patches were generally considered Category 3 (larger patches, better condition) and Category 4 (small patches). Wheat and other cultivated lands were considered Category 6.

In terms of the habitat categories, Table 3.3 illustrates in this example the amount of habitat estimated to be within 750 feet of facilities, as well as the acres considered temporarily and permanently impacted by the facility. In this particular example, most of the project facilities were located in cultivated (Category 6) lands (>90%), with less than 11 acres of Category 3 and 4 habitats (primarily CRP) permanently impacted by the facility. The acres permanently impacted by the project are required to be mitigated under the Oregon Energy Facility Site Evaluation Council (EFSEC) rules, and these calculations and habitat ratings are used to determine habitat mitigation strategies (Oregon EFSEC 2009).

**Table 3.1. Land cover types and categories in the study area.**

| Land Cover | Cover Subtype | Map Code | Land Cover Categories and Description |
|---|---|---|---|
| Agricultural | Non-Irrigated Cropland | AG | 6-Cultivated croplands with low potential to become essential or important habitat. |
| | Conservation Reserve Program | CRP | 3-Croplands planted to grassland/shrub-steppe in the CRP program that provide important wildlife habitat.<br>4-Croplands planted to grassland/shrub-steppe in the CRP program that lack later seral stage vegetative communities or are of less importance as wildlife habitat due to land management or topographic locale. |
| Riparian | Riparian Trees | RT | 2-Essential and limited habitat for wildlife (documented nest/roost habitat). |
| | Intermittent Streams | WS | 3-Essential or important fish and wildlife habitat which is limited. |
| | Intermittent Streams/ Riparian Trees | WS/RT | 2-Essential and limited habitat for fish and wildlife (documented nest/roost habitat). |
| Upland | Upland Trees | UT | 1-Irreplaceable, essential habitat for a wildlife species (i.e., Swainson's hawk) and limited within a physiogeographic province (documented food/cover/nest habitat and active nest).<br>3-Essential or important habitat for wildlife that is limited. |
| Shrub-Steppe | Sagebrush/ Shrub-Steppe | SS | 2-Essential and limited wildlife habitat (relatively undisturbed old-growth shrub structure; moderate grazing).<br>3-Essential or important wildlife habitat which is limited (e.g., relatively undisturbed habitat; moderate grazing).<br>4-Important wildlife habitat (e.g., moderate-heavy grazing and/or weedy habitat). |
| Grassland-Steppe | Grassland | GR | 3-Essential or important wildlife habitat which is limited (e.g., relatively undisturbed habitat; moderate grazing).<br>4-Important wildlife habitat (e.g., moderate-heavy grazing or weedy habitat). |
| Developed | Developed | DE | 6- Low potential to become essential or important habitat (e.g., residences, storage bins, farm equipment storage, grain elevators, industrial/commercial facilities, gravel quarries). |
| Surface Water | Ponds | WP | 3-Essential or important wildlife habitat which is limited (wetland features). |

Habitat categories and map codes correspond with the locations of each habitat (see Figure 3.1).

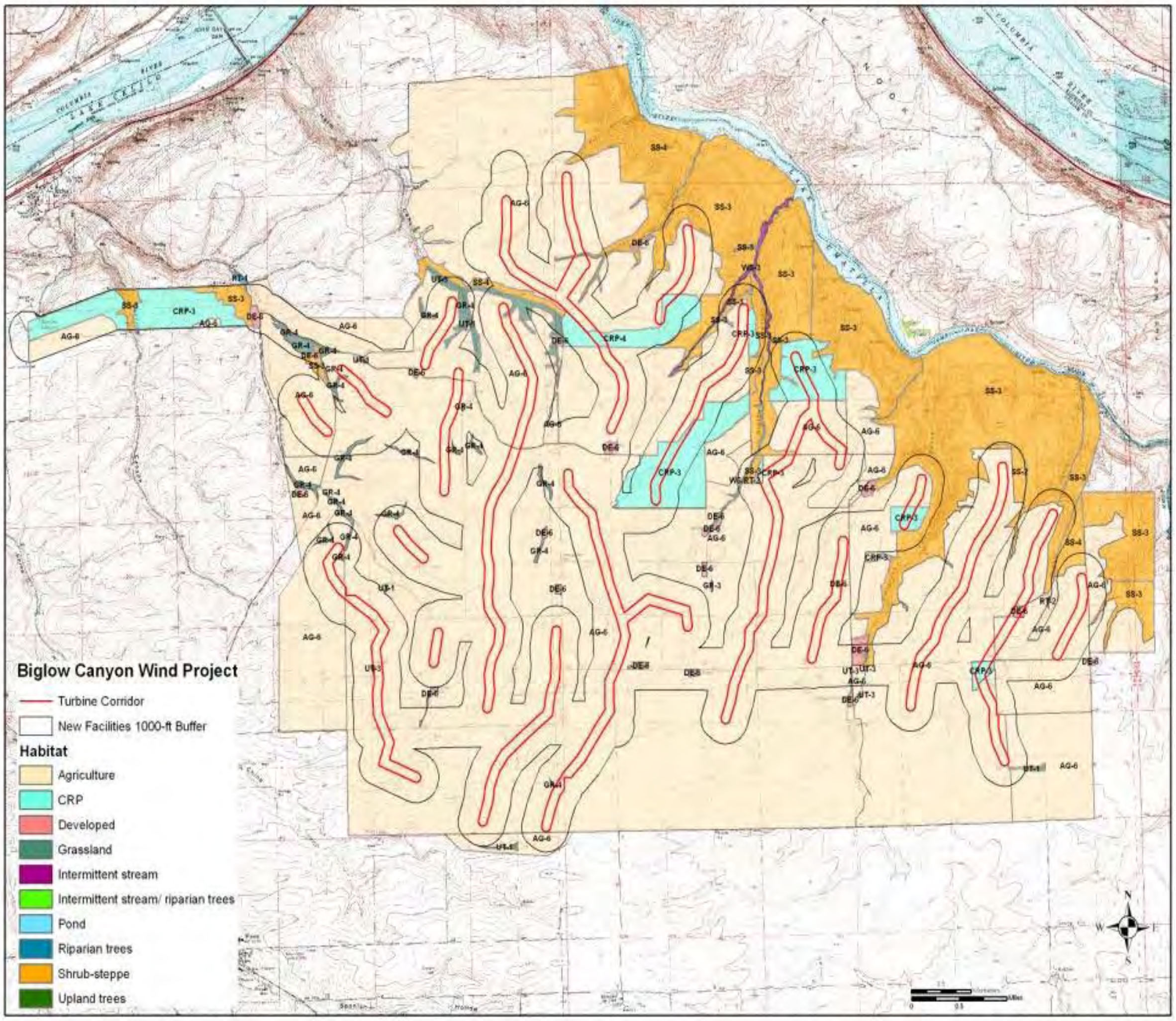


**Figure 3.1. Habitat (land cover) types and categories in the study area. Habitat categories and map codes correspond with the locations of each habitat (see Table 3.1; WEST 2005).**

**Table 3.2. Land cover types, coverage, and composition, based on habitat mapping within the study area.**

| Habitat | Square Miles | % Composition |
|---|---|---|
| Non-Irrigated Cropland | 10,682.92 | 83.4 |
| Conservation Reserve Program (CRP) | 435.51 | 3.4 |
| Riparian Trees | 38.43 | 0.9 |
| Intermittent Streams | 5.13 | 1.1 |
| Intermittent Streams/Riparian Trees | 76.86 | 0.8 |
| Upland Trees | 5.10 | 0.9 |
| Sagebrush/Shrub-Steppe | 1,027.31 | 8.0 |
| Grassland | 320.23 | 2.5 |
| Developed | 192.14 | 1.5 |
| Ponds | 25.62 | 1.2 |
| **Total** | **12,809.25** | **100** |

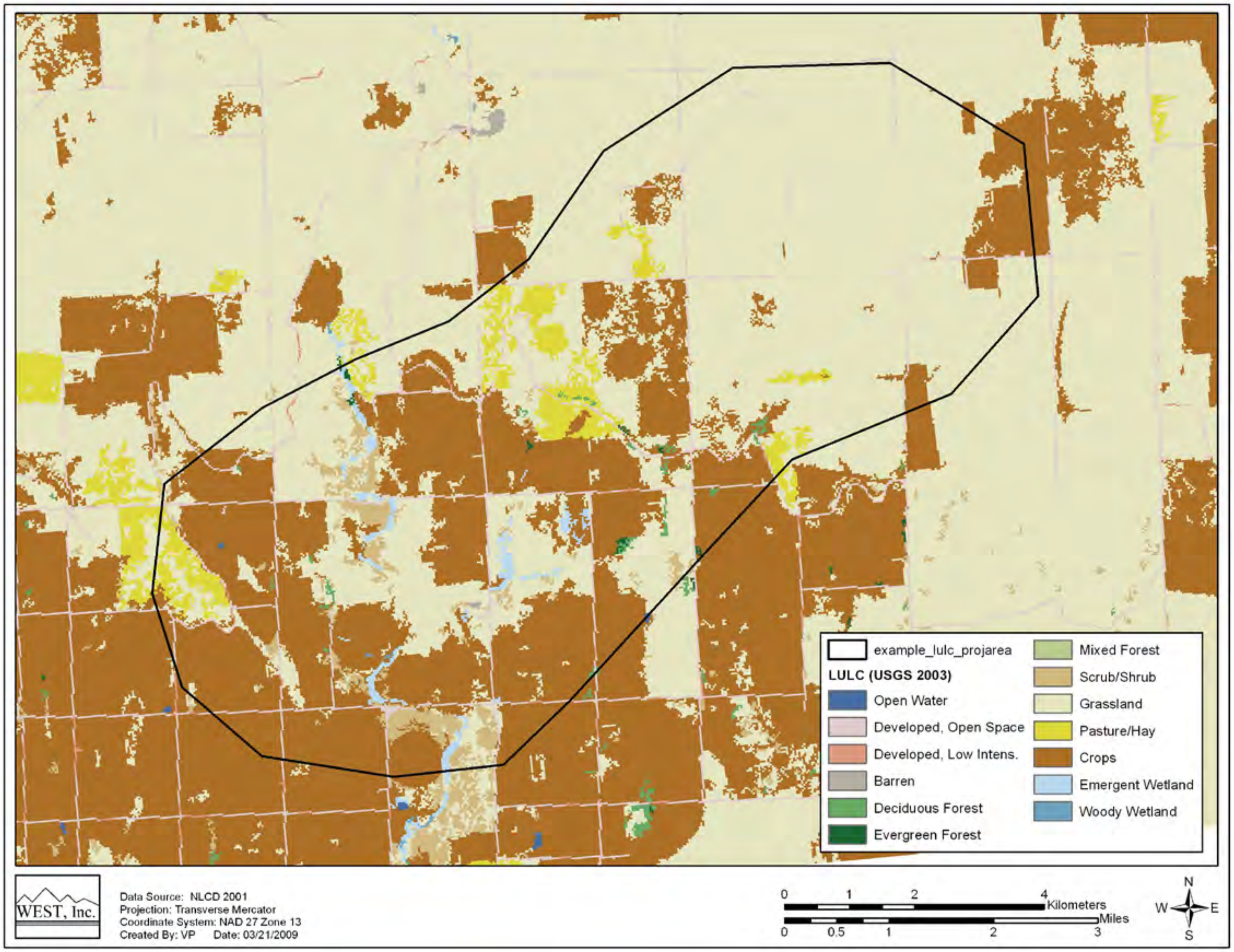


**Figure 3.2. The land cover types and coverage within the study area (USGS NLCD 2001).**

**Table 3.3. Total habitat acreage within potential impact zone, and estimated quantity of disturbance or loss of categorical habitats and associated habitat types within the facility**

| | | Impacts | |
|---|---|---|---|
| | Total Acres (within 750 feet of facilities) | Temporary Facilities[1] (acres disturbed) | Permanent Facilities[2] (acres lost) |
| **Category 1** | **2.64** | **0.00** | **0.00** |
| Upland Trees[3] | 2.64 | 0.00 | 0.00 |
| **Category 2** | **13.73** | **0.00** | **0.00** |
| Intermittent Stream/Riparian Trees | 0.18 | 0.00 | 0.00 |
| Riparian Trees | 0.08 | 0.00 | 0.00 |
| Shrub-steppe | 13.47 | 0.00 | 0.00 |
| **Category 3** | **931.47** | **13.57** | **7.35** |
| CRP | 709.56 | 12.40 | 7.18 |
| Shrub-steppe | 215.96 | 1.17 | 0.17 |
| Intermittent streams | 0.22 | 0.00 | 0.00 |
| Upland trees | 5.47 | 0.00 | 0.00 |
| Pond | 0.26 | 0.00 | 0.00 |
| **Category 4** | **313.2** | **4.12** | **3.62** |
| CRP | 138.31 | 3.06 | 2.70 |
| Shrub-steppe | 38.80 | 0.06 | 0.04 |
| Grassland | 136.09 | 1.00 | 0.88 |
| **Category 5** | **0.00** | **0.00** | **0.00** |
| **Category 6** | **10,430.12** | **356.92** | **154.91** |
| Developed | 64.43 | 3.97 | 4.58 |
| Agricultural | 10,365.69 | 352.95 | 150.33 |
| **Total** | **11,691.16** | **374.746** | **165.88** |

[1] Temporary facilities include: access roads, construction areas, access for overhead line construction, installation sites for underground collector cables, and equipment laydown areas for individual turbines, entire strings of turbines, and laydown areas for in-transit towers, cranes, and miscellaneous construction equipment.

[2] Permanent facilities include: turbine pads and towers, substation and alternate substation, meteorological towers, O&M facility, and permanent access roads.

[3] Habitat with active Swainson's hawk nest (2004 and 2005).

### Modeling Collision Risk

Collision risk models have been used for predicting potential collision risk mortality of birds at wind projects. These models can be useful in cases when little empirical data on collision potential for a species or group of species are known (Podolsky 2004). For example, if there is a concern over the potential collision risk of a rare species that may pass over a wind project, but insufficient or non-existent empirical mortality exists for the area and the species, these models may be useful in estimating potential risk. In addition, in cases where there is potential take of an ESA listed species, these models have been used to predict potential take, in development of Habitat Conservation Plans (Kaheawa Wind Power 2006). Collision risk models may be the only practical means for estimating risk when there is inadequate empirical data to predict risk (e.g., offshore wind energy development).

While different approaches have been used to model collision risk, most use the following information to determine potential collision: wind facility characteristics including the number, type, size of the wind turbines; layout of the wind turbines; wind speed and direction; and species characteristics such as passage rates, flight height, flight speed, and other behaviors (e.g., avoidance). In general, model output is particularly sensitive to avoidance probabilities (Chamberlain et al. 2006). Existing models account for avoidance in different ways (e.g., Podolsky 2004, Band et al. 2006). Even Tucker's (1996) model for flight through active rotors allows for fine-scale avoidance of approaching blades.

The following example illustrates one modeling approach for collision risk.

*Example*

An individual-based mathematical model was developed for the estimation of the probability of bird collisions with wind turbines at a hypothetical wind project. The model incorporated Tucker's (1996) approach for estimating the probability of a bird colliding with the rotor blades of a wind turbine. In addition to rotor collisions, the model allowed for estimating the probability of birds colliding with the turbine tower and nacelle. The physical and dynamic characteristics of the proposed turbines as well as the spatial arrangement of the individual turbines within the wind park were incorporated in the model. Species characteristics including size, flight altitude and speed, and avoidance behaviors were based on literature reviews. Wind characteristics were based on data collected from meteorological towers at the site. Collision probabilities were assessed by simulating flight paths of individual birds through the hypothetical wind facility and calculating the proportion of all such paths that resulted in collision. Predicted numbers of fatalities were then calculated by multiplying collision probabilities by passage rates.

Results presented here represent an analysis based on a number of simplifying assumptions described in greater detail below.

Assumptions

*Turbines*

We used a generic 3 MW turbine, with characteristics based on typical manufacturer specifications (Table 3.4). Each tower was modeled as a monopole with diameter that tapered smoothly from the base to the top. Dynamic characteristics of the turbines were based on operational data from wind turbines at an existing project. These characteristics included the relationship between wind speed and both rotational speed and blade pitch. Operational data indirectly reflect manufacturer specifications for rated rotational speed (typical speed under most wind conditions), cut-in wind speed (the minimum wind speed at which the rotor begins to turn), cut-out speed (the maximum wind speed at which the rotor turns; at greater wind speeds, the rotor is disengaged for safety reasons), and the rated wind speed (the speed at which the rotor reaches rated rotational speed; see Figure 3.3). When conditions were such that rotors were turning, the Tucker sub-model was used to estimate rotor collision probability. Otherwise, when rotors were not turning (e.g., because wind speed exceeded the cut-out speed), collision probabilities were estimated with a 3-dimensional geometric model of the rotor. The model also accounted for avoidance of and collision with turbine towers and nacelles.

**Table 3.4. Turbine characteristics used in the collision model.**

| Feature (dimensions) | Value |
|---|---|
| Tower diameter (m) | |
| Base | 3.7 |
| Top | 2.3 |
| Tower height (m) | 77.5 |
| Nacelle (L×W×H, m) | 9.65 × 3.60 × 4.05 |
| Hub height (m) | 80 |
| Rotor radius (m) | 45 |
| Cut-in wind speed (m/s) | 3.5 |
| Cut-out wind speed (m/s) | 25 |
| Rated wind speed (m/s) | 16.1 |
| Minimum rotational speed (rpm) | 8.6 |
| Rated rotational speed (rpm) | 16.1 |

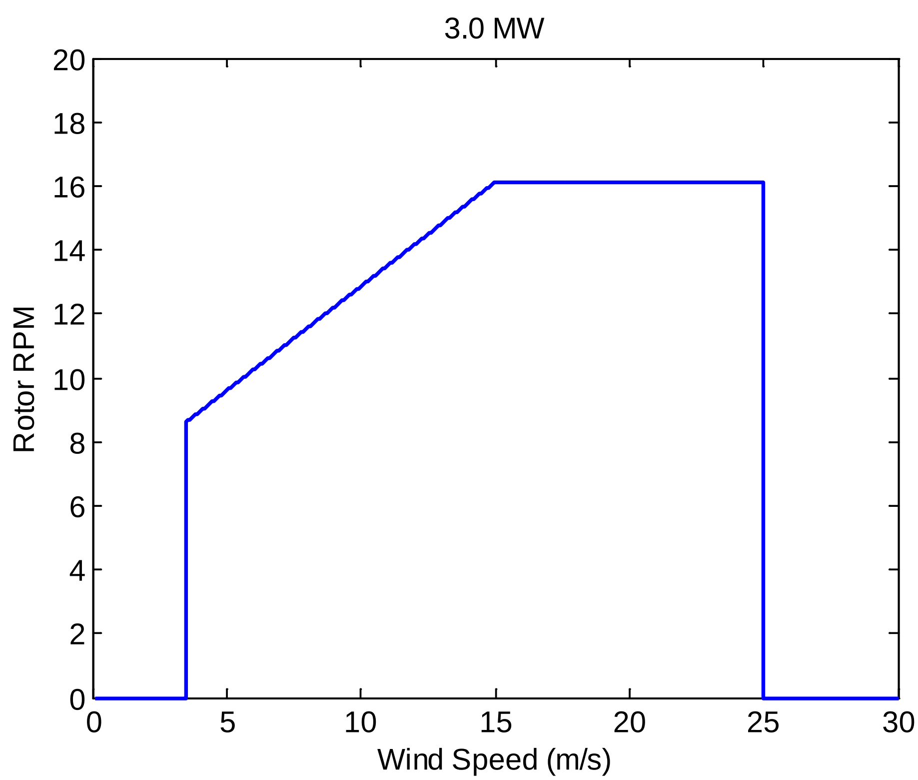


**Figure 3.3. Relationship between wind speed and rotor speed for the collision model for the Vestas V90 3 MW turbine.**

*Wind Facility*

A proposed layout of the wind facility for this example consists of an array of regularly spaced turbines with the longer axis oriented north to south (Figure 3.4).

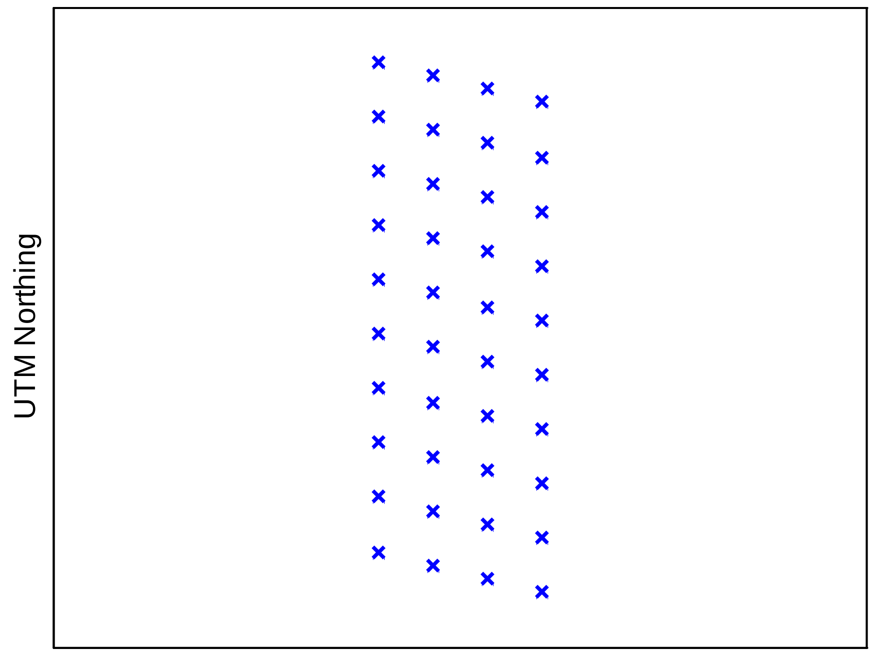


**Figure 3.4. Turbine layout.**

*Wind Characteristics*
Wind direction (Figure 3.5) and speed were obtained from meteorological towers at an existing project. During simulations (described in greater detail below), hourly wind observations of direction and height-adjusted speed were randomly sampled from the available data for a particular season and period of the day.

*Bird Characteristics*
The particular species for this example was assumed to have a wing span of 0.22 m and body length of 0.15 m. Body size was held constant for all individuals in all simulations. Simulated flight speeds had a mean of 12.5 m/s and were generated from a modified Gamma (4.8, 2.6) distribution (Figure 3.6).

Radar studies were used to inform a distribution of flight directions for each season (each season's distribution was constructed as a mixture of normal distributions, but wrapped around a circle [von Mises distribution; Fisher 1995] to fit the observed data). Assigned direction was fixed during each simulated flight. That is, flight path direction did not change in response to wind or other conditions. Encounter with turbine structures could induce temporary changes in direction if the structure was avoided, but original direction was maintained following avoidance.

On-site data on flight heights would be the preferred method for simulating flight height distributions. In this example, two alternative lognormal distributions (Figure 3.7, Table 3.5) were used to approximate the observed distribution

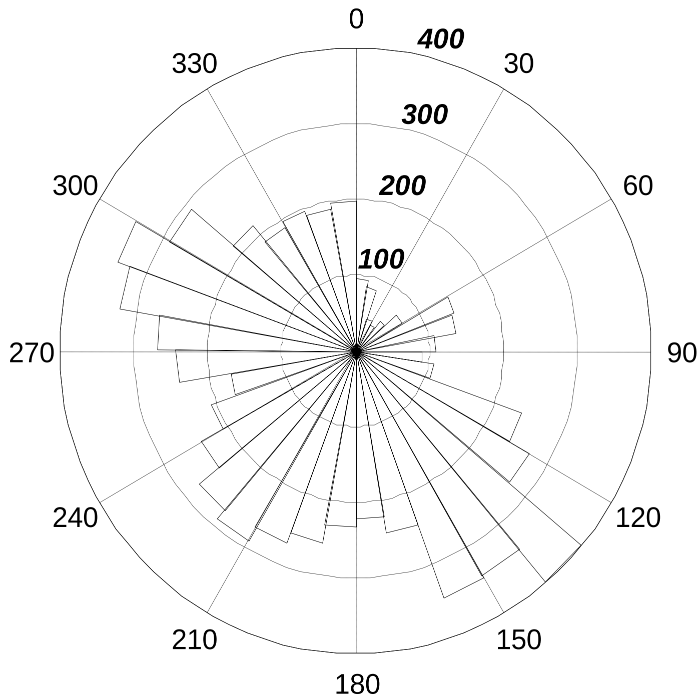


**Figure 3.5. Rose plots (circular histograms) of wind direction for the collision model.**

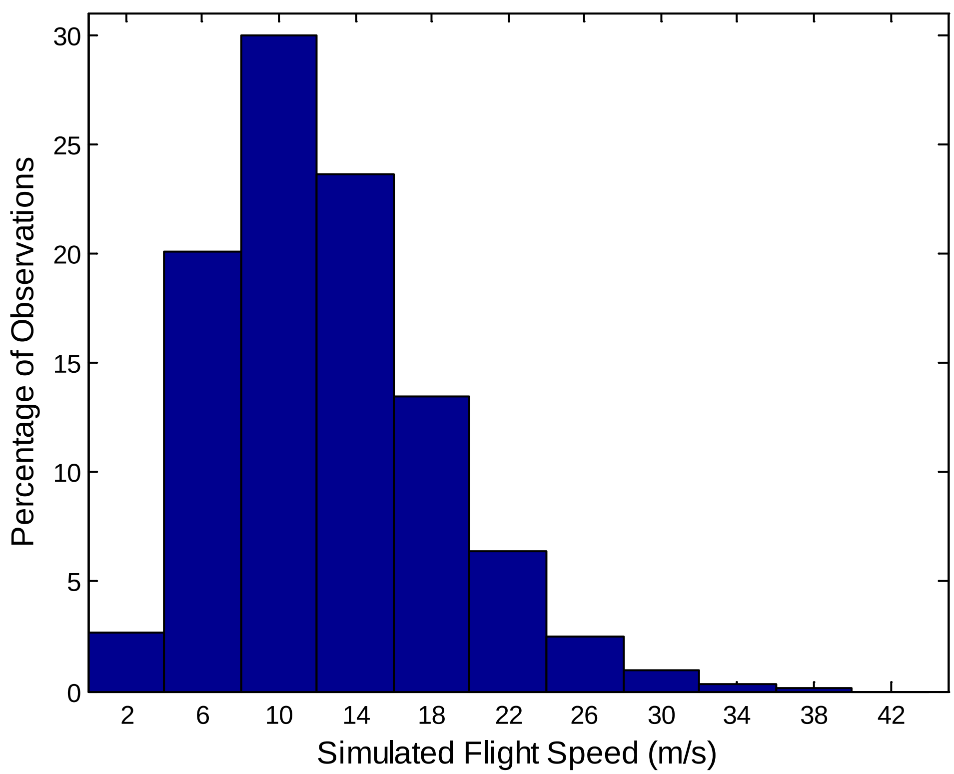


**Figure 3.6. Distribution of simulated flight speeds.**

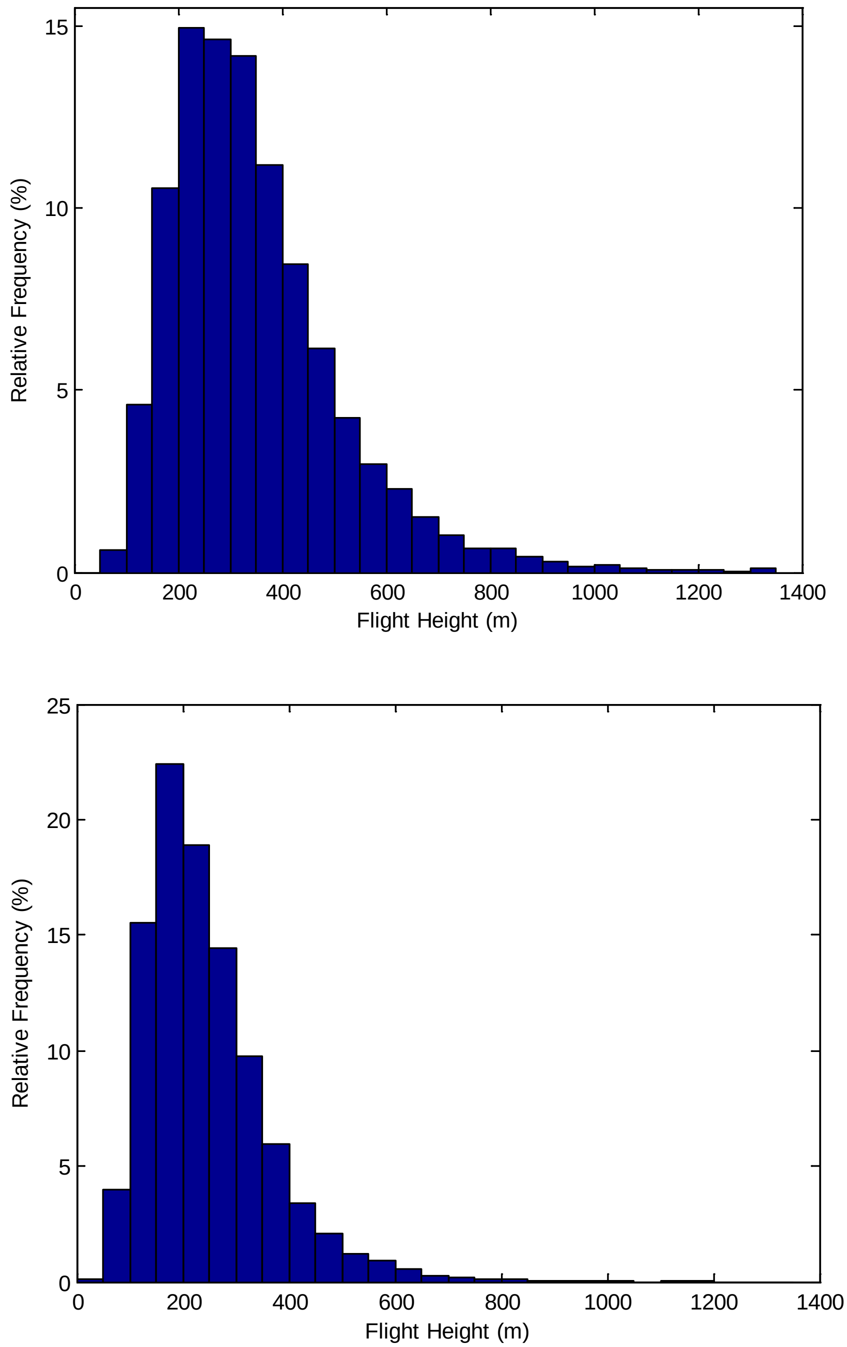


**Figure 3.7. Histograms depicting lognormal distributions of flight height used in simulations for the collision model. Top panel corresponds to "High" in Table 3.5; bottom panel corresponds to "Low".**

**Table 3.5. Lognormal distributions of flight heights for simulation of species of interest in the collision model.**

| Distribution | Lognormal Parameters μ | σ | Mean (m) | SD (m) | Proportion Below Max Rotor Height[1] |
|---|---|---|---|---|---|
| High | 5.75 | 0.45 | 346.9 | 164.7 | 0.020 |
| Low | 5.39 | 0.45 | 242.6 | 114.9 | 0.106 |

[1] Proportion of the distribution at risk of collision, not considering other factors such as avoidance probabilities.

*Avoidance*

Bird avoidance was modeled at several levels. The entire wind facility might be avoided by some birds. If a flight path entered the wind facility, then avoidance was evaluated as individual structures – rotor, tower, or nacelle – were encountered. While failure to avoid a tower or nacelle necessarily resulted in a collision, failure to avoid the rotor-swept area did not imply a collision. Encounter of the rotor-swept area invoked the Tucker's (1996) model which might allow a bird to pass unharmed.

Probability of wind facility avoidance was simulated at three values: 0.5, 0.75, and 0.9. That is, in the worst case, 50% of simulated birds avoided entering the wind facility while in the best case, 90% of simulated birds did so. We note that this range of values is supported by the recent evidence from studies of offshore wind facilities in Denmark (Petersen et al. 2006), which indicates that up to 90% of all birds avoided entering the wind facilities. Lower avoidance probability (0.5 in this example) would be expected during periods of low visibility.

Tower and nacelle avoidance probabilities were simulated at three values: 0.75, 0.9, and 0.99. In clear conditions, avoidance of fixed structures is likely to be extremely high (very close to 100%). As with wind facility avoidance, a low value was chosen to account for poor visibility during low light and heavy fog conditions.

The probability of rotor avoidance was simulated at two values: 0.25 and 0.50.

*Tucker Model*

As expressed by Tucker's (1996) model, the probability that a bird will collide with a rotor blade depends on bird air speed, bird size, angle of approach (whether downwind, upwind, or crosswind), wind speed, blade angular speed, location on the rotor disc that is intersected by the flight path, blade chord length, blade twist angle combined with blade pitch, and wind velocity loss through the rotor disc due to energy extraction (a characteristic of turbine design). In addition, Tucker's model accounts for evasive maneuvering by the bird such that collision probability may be lower nearer the hub where blade tangential velocity is lower.

*Simulation Protocol*

For each simulation, the initial number of birds was adjusted to ensure that an adequate number of bird flights passed through the wind facility at heights within the zone of risk (i.e., below the maximum rotor height). More specifically, the initial number was chosen such that on average, at least 100 birds would have been at direct risk of colliding with a turbine.

A simulation consisted of 1,000 iterations. At the onset of each iteration, several steps were followed based on the selected simulation parameters: (1) wind speed and direction were randomly selected from the meteorological tower data based on the chosen season and period of the day; (2) turbines were rotated to face into the wind, and turbine rotational velocity was calculated from the selected wind speed; (3) flight heights were generated for all birds from the appropriate lognormal distribution (Figure 3.7); (4) air speeds were independently selected for all birds at risk by generating random variates from the specified Gamma distribution; (5) flight directions were independently selected for all birds at risk by generating random variates from the mixture of von Mises (circular normal) distributions (Fisher 1995) for the appropriate season; (6) for each direction of approach to the wind park, bird flight path origins were randomly generated from a Uniform distribution across the “width” of the facility.

Estimated passage rate through the site was 50 birds per day for 45 days in the spring and 45 days in the fall, or 4,500 birds per year. Fatality estimates were calculated as the product of collision probability and passage rate for all simulation conditions.

*Results and Conclusions*
The sensitivity of overall collision probability to the different avoidance factors is shown in Figure 3.8. Among these factors, collision probability was most sensitive to wind facility avoidance. That is, over the range of input values used in these simulations, changes in wind facility avoidance led to the greatest changes in collision probability. Sensitivity to flight altitude (not shown) was nearly as great as wind facility avoidance.

For this example, the average total collision probability across all simulations was 0.0000556, such that less than 6 out of every 100,000 bird flights would be expected to collide with a turbine. Given the estimated passage rate through the wind park (4,500 birds per year), this probability translates to 0.25 expected fatalities per year, or 1 every 4 years.

Using the most conservative assumptions regarding avoidance (lowest avoidance probabilities), but the flight altitude assumption that closely matches the data (High), we estimate less than 1 fatality per year.

In the worst case considered here, mean total collision probability was approximately 0.0003, such that 3 out of every 10,000 bird flights would be expected to collide with a turbine. Given the estimated passage rates through the wind facility, this probability of collision translates to 1.35 expected fatalities per year or 27 fatalities over a 20-year period.

These simulations are used to provide some information on potential fatalities and use as much data as are available regarding bird behaviors and abundance near the project area, as well as other studies of avoidance by other species. This modeling approach should be evaluated with actual fatality data.

## BATS

Interactions between bats and wind turbines are poorly understood (NRC 2007, Kunz et al. 2007b). The combination of nocturnal habits, volancy, small size, and variation in resource dependence (species vary in roost, water, and food resource dependence), have made even a rudimentary understanding of how bats interface with their environment difficult to establish (Gannon et al. 2003). Post-construction monitoring generally has provided most of the information that has been gathered on bat fatalities at wind facilities. While patterns of fatality of bats at wind facilities allow for some conjecture about risk factors for some species, information on use of the area encompassing a facility are needed to place bat fatality in an appropriate context (Fiedler 2004).

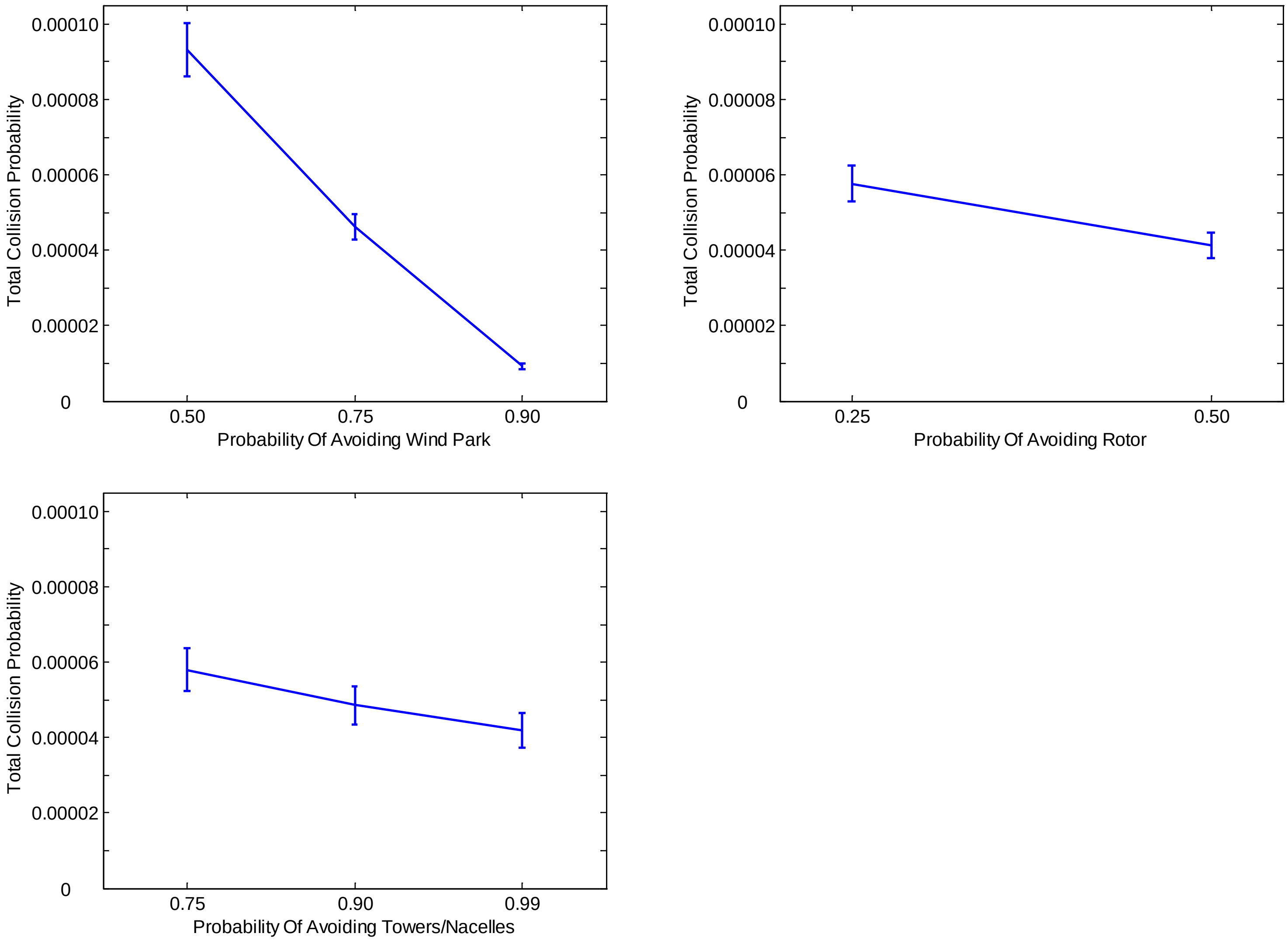


**Figure 3.8. Total collision probability (mean ± 1 standard error), as a function of avoidance: wind facility avoidance probability, rotor avoidance probability, and tower/nacelle avoidance probability for the collision model.**

Pre-construction studies at wind facilities have been conducted and most commonly employ mist nets and acoustic detectors to assess local bat species presence and activity. However, using this information to predict bat fatality and risk at a site has proved to be challenging. The ability to generate reliable risk assessments prior to construction of wind facilities is greatly hampered by the lack of baseline data on bat population distributions and densities throughout much of North America (O'Shea et al. 2003, Reynolds 2006) and by the migratory patterns and behavior of bats (Larkin 2006).

Available techniques for assessing bat activity in pre- and post-construction studies include roost surveys, mist-netting, acoustic detectors, radio telemetry, thermal imaging, and radar. Here, we focus primarily on roost surveys, mist-netting, and acoustic detectors to assess bat activity and potential risk. Radar and thermal imaging are covered in other sections of this document. We also refer readers to an extensive review on nocturnal methods and metrics by Kunz et al. (2007a; see Appendix A of this document) for more detailed information on each of these methods.

**Acoustic Monitoring**

Acoustic monitoring is perhaps the most practical method for monitoring bats at proposed wind facilities (Kunz et al. 2007a). Acoustic monitoring allows researchers to detect and record calls of echolocating bats, and can be used to assess relative activity and identify species or groups of species. Estimating amount of activity is relatively straightforward, but estimating abundance requires differentiation between multiple passes of a single bat and multiple bats making single passes, and is not usually possible. Echolocation calls are reliably distinguishable from other sounds (e.g., bird, arthropod, wind, mechanical), but ability to distinguish species of bats varies with taxon, location, type of equipment, and quality of recording, and may be challenging (Barclay 1999, Hayes 2000, NRC 2007).

Understanding bat activity levels prior to construction of wind facilities can assist in identifying habitats and features that may pose high risk of fatality, and may aid with decision-making, including specific placement of turbines (Fiedler 2004, Reynolds 2006, Arnett et al. 2006). Unfortunately, past and current efforts to monitor bat activity acoustically prior to construction of turbines may suffer from flaws in study design, including small sample sizes and poor temporal and spatial replication (Hayes 1997, 2000), pseudoreplication (Hurlbert 1984), and inappropriate inference because limitations and assumptions were not understood or clearly articulated (Hayes 2000, Sherwin et al. 2000, Gannon et al. 2003). Also, there is a lack of information and lack of agreement among stakeholders, biologists, and scientists as to what constitutes different levels of risk in relation to bat activity and potential fatality of bats at wind facilities. Passive acoustic surveys can provide baseline patterns of seasonal bat activity at proposed wind energy sites, but given the current state of knowledge about bat-wind turbine interactions, researchers should be aware of the fundamental gap between pre-permitting assessments and operations fatalities. The ability to predict fatalities, and thus risk, from acoustic data has not yet been established, and acoustic data gathered pre-construction should be linked with post-construction fatality data from multiple facilities (Arnett et al. 2006). Several studies are underway, however, and this linkage should be developed soon. Kunz et al. (2007a; see Appendix A of this document) provide extensive details on methods and metrics for using acoustic detectors. Below, we provide an additional guide to study design and deployment considerations, study duration, and modeling bat activity relationships.

Bats are widely distributed and are likely present at most proposed wind facilities. Discussions with experts, state wildlife agencies, the USFWS and perhaps other federal agencies, depending on project location, will be needed to assist in the determination of the credibility and applicability of any existing data on bat occurrence. Acoustic monitoring for bats may be necessary to confirm bat presence when available data are inadequate.

Choice of experimental design for acoustic monitoring is contingent on a number of factors and depends on the question of interest. The typical questions addressed by acoustic monitoring of the study area include species presence and relative abundance. These data can be weighed in the final decision on whether and how to develop a site. Acoustic data also may be used to predict post-construction fatalities based on pre-construction activities. Control sites and employment of BACI designs (Green 1979, Anderson et al. 1999, Morrison et al. 2001; Morrison et al. 2006) usually are necessary when attempting to relate changes in activity associated with characteristics of a wind facility prior to and after construction. For example, bats may be attracted to a site once turbines are constructed (Ahlén 2003; Arnett et al. 2007b, 2008; Kunz et al. 2007b) and a BACI design would indicate if changes between pre- and post-construction bat activity could be attributed to the presence of turbines. Researchers conducting acoustic monitoring should clearly state questions, definitions and assumptions prior to beginning monitoring. Hayes (2000), Sherwin et al. (2000), and Gannon et al. (2003) provide information on assumptions and limitations of acoustic monitoring studies.

Temporal and spatial variation in bat activity must be accounted for when designing field studies in order to assess bat activity at proposed and existing wind facilities. High spatial variability in bat activity, both in the vertical and horizontal plane, has been demonstrated both within and among sites (Hayes 1997; Gannon et al. 2003; Arnett et al. 2006, 2007a; Redell et al. 2006; Reynolds 2006). Furthermore, indices of activity generated from acoustic detectors are well known to vary temporally, including within and among nights, seasons, and annually (Hayes 1997). An initial site assessment using bat detectors may yield little or no evidence of bat activity at a proposed wind-development area. Thorough temporal sampling would be needed to assess the existence of possible seasonal pulses of activity from migration. Sensitivity among acoustic detectors should be calibrated, following Larson and Hayes (2000). Differences in detected activity also could be due to differences in probability of detection rather than actual differences in activity (Humes et al. 1999, Hayes 2000, Gannon et al. 2003, O'Shea et al. 2003, Duchamp et al. 2006). Within forests, several factors can influence detectability of bat calls (Hayes 2000, Weller and Zabel 2002). Differences in vegetative clutter may deflect echolocation calls to different degrees (Patriquin and Barclay 2003) and vertical structure of a forest may influence the height at which bats forage (Kalcounis et al. 1999, Weller and Zabel 2002, Duchamp et al. 2006). Changes in vegetation cover and conditions from pre-construction to post-construction also may alter the height at which bats fly, and thus lead to more bats feeding, commuting, or migrating through an area, thus potentially increasing exposure risk with turbine rotors. These factors must be considered when designing acoustic studies, analyzing data, and interpreting findings. Notwithstanding, with current understanding of bat biology, it is impossible to conclude that the absence of bat activity on one or a few nights of recording indicates that bats are absent from the site.

Long-term passive monitoring with acoustic detectors requires that the equipment be resistant to damage from weather (e.g., rain, hail, fog). A common approach for acoustic microphones is to protect them within a weather-proof PVC "bat hat" that is linked by cables to ground-based data-logging units. When installed, the microphone points downward and receives signals from a clear Lucite or Plexiglas reflector plate (e.g., Arnett et al. 2006, 2007a; Redell et al. 2006; Kunz et al. 2007a). There is concern that both quantity and quality of calls recorded by detectors using bat-hat systems is compromised. More research is needed to determine if such bias exists and what effect there is on call quantity and quality and subsequent predictability of fatalities. Researchers should deploy the same detector systems and weatherproofing devices to ensure that data collection, and any bias (if it exists) are consistent. Acoustic detectors provide an index of activity and if bias is generally consistent, then compromises to call quantity and quality may not affect predictability of fatalities.

Sample size requirements will vary depending on variability of activity among bats at a given site. For projects in the eastern United States, deploying detectors on all existing meteorological towers available at the proposed site may be necessary, whereas a sample of existing meteorological towers for sampling may be appropriate at other sites where variation in bat activity among sampling stations is low. For example, in eastern hardwood deciduous forests, researchers estimated that 18 sampling stations would be required to achieve precision of activity indices within 10% of the mean of their original dataset (10 stations would be required to be within 20% of the mean; Figure 3.9, E.B. Arnett, Bat Conservation International [BCI; http://www.batcon.org], unpublished data). Conversely, Weller (2007) reported little variation in bat activity indices among sampling stations at a proposed site in Palm Springs, California, and suggested the sample of 4 meteorological towers used during that study adequately accounted for the variation in bat activity. Researchers should use existing data from studies in similar regions and habitats to estimate sample sizes needed to get reasonable estimates of bat activity at future proposed sites.

When studying bats in warmer climates, monitoring is recommended for a full year because so little is known about the timing of bat migratory activity; some bat species overwinter in warmer regions and can be active throughout the year. Year-long surveys may be particularly important if sites are likely to support resident bat populations and include habitat features conducive to higher potential risk (e.g., near hibernacula or maternity roosts). When studying bats in colder climates, surveys should be conducted during the full period of activity for bats (generally April through October; Arnett et al. 2006, 2007a; Kunz et al. 2007a). If year-round or full activity season surveys are conducted, acoustic monitoring should be conducted at least during spring and fall migration, periods that pose the greatest risk to bats (Arnett et al. 2008). Detectors should be set to record bat calls from at least ½ hour before sunset to ½ hour after sunrise each day during the survey period.

***Modeling patterns of bat activity.*** Studies should be designed to estimate activity rates (number of calls/tower) of bats, and differences in those rates generally will be based on three factors: species or species group (e.g., those with high and low frequency calls); habitat variations (e.g., forest vs. open field); and height above the ground (e.g., 1.5 m, 25 m, 50 m). Bats of different species groups might prefer one land cover over another and might have different preferred flight heights, or preferred flight height might differ with habitat. Other studies have reported that activity rates can differ with temperature and wind speed (e.g., Reynolds 2006), but how these latter two factors might affect activity patterns of species groups is currently unknown.

Models can be developed to help understand the relationship between bat call rates and independent variables such as temperature, habitat, height above ground, wind speed and other possible variables. These models can aid in understanding the potential risk of collision of bats with wind turbines and in determining when and where they might be most at risk. With these types of model selection applications, a set of plausible models should be developed (Burnham et al. 2004) describing the interaction of temperature and wind speed with each of several possible species-specific parameters (e.g., species group, flight height, and habitat). Date and the quadratic effect of date can be included in models to account for the seasonal nature of bat activity that likely peaks in late summer and fall (Arnett et al. 2006, 2007a). Although these data are counts (i.e., number of passes per night in each factor combination) and would naturally be modeled as a Poisson distribution, the observed values may have more variation than would be expected of Poisson-distributed data. Thus, it may be necessary to model acoustic data as over-dispersed Poisson using a generalized linear model.

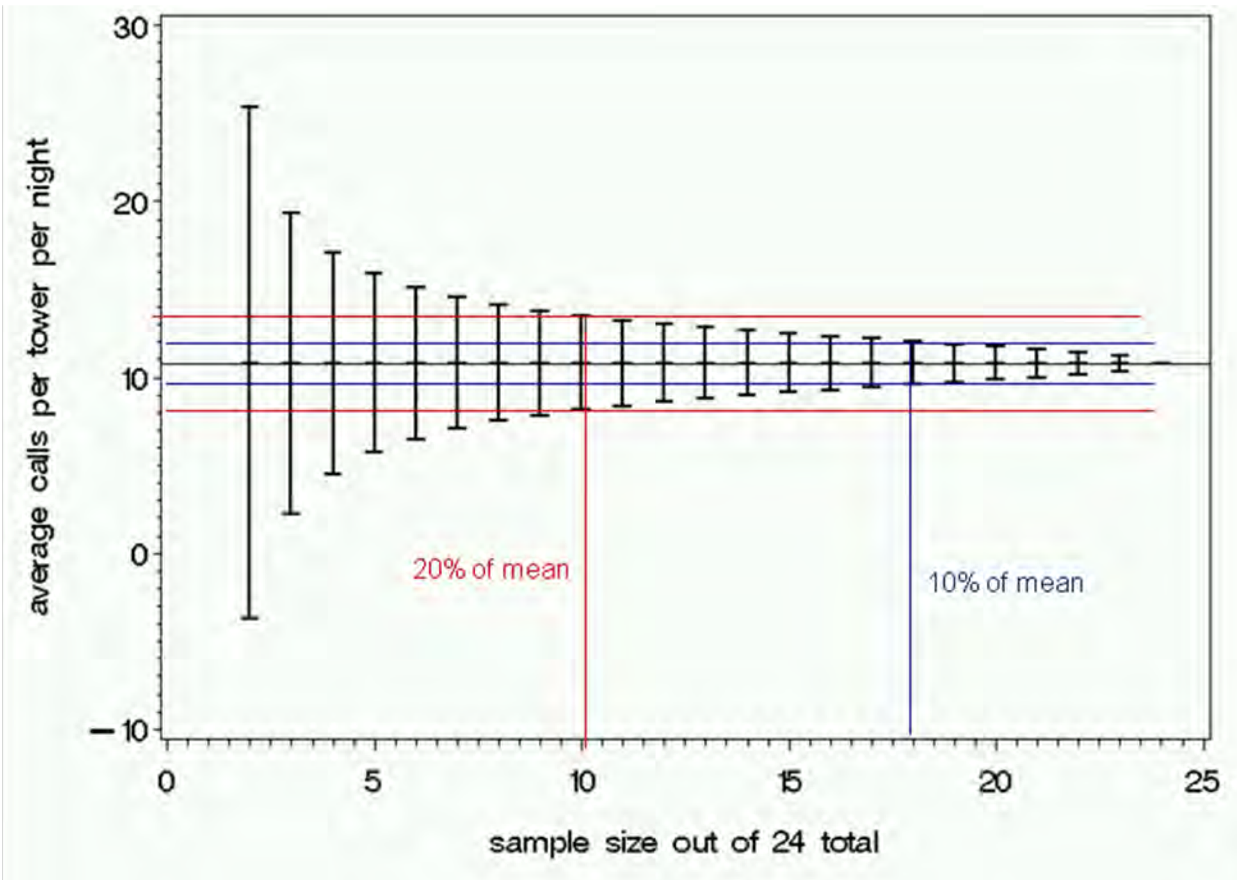


**Figure 3.9. Average number of calls per tower per night collected at 15 sampling stations at the Casselman Wind Project in south-central Pennsylvania, 1 August to 31 October 2005, and the number of sampling stations needed to achieve 10% and 20% of the mean generated from this data set (from Arnett et al. 2009a).**

**Other Study Methods Applicable to Bats**

Other research tools are available to complement the information from acoustic surveys. These methods typically are not used for pre-construction baseline studies and are more appropriate for in-depth studies that might be conducted post-construction. Nevertheless, these methods may be helpful to answer particular questions about threatened or endangered species such as roosts size, species composition, and bat behavior and activity patterns at roosts. Kunz et al. (2007a) provides a comprehensive description of bat survey techniques pertinent to wind facilities. Methods for assessing colony size, demographics, and population status of bats can be found in O'Shea and Bogan (2003). Kunz et al. (2007a) and Kunz and Anthony (1996) provide detailed guidelines on capture techniques for bats, including mist-nets and harp traps. Devices and methods used to capture bats also have been thoroughly discussed elsewhere (see reviews in Kunz and Kurta 1988, Kunz et al. 1996, 2009a, 2009b), so only a brief overview of methods is provided here. Although no single capture method is suitable for all species, mist nets and harp traps are the devices used most commonly used for bats because they are relatively easy to deploy and can be used in a variety of situations.

***Mist-Netting.*** Mist-netting of bats is required in some situations by state agencies and the USFWS to determine the presence of threatened, endangered or otherwise rare species. Mist netting alone may be inadequate for assessing bat presence at proposed and operational wind energy facilities, and we generally do not recommend this technique as a standard method for assessing risk of wind development to bats because: (1) the technique measures captures of bats per unit effort, therefore only providing an index of abundance; (2) not all proposed or operational wind energy facilities offer conditions conducive to capturing bats and often the number of suitable sampling points is minimal or not closely associated with the project location; and (3) capture efforts often occur at water sources offsite or at nearby roosts and the results may not reflect species presence or use on the site where turbines are to be built. Notwithstanding, mist-netting and harp-trapping are the only available methods that can provide reliable information on sex, age and reproductive condition (Kunz et al. 2007a, 2009a). Captures of bats near roost sites and in habitats below and adjacent to wind turbines may provide valuable information on population variables of interest. Captured bats provide tissue samples for DNA and stable isotope analyses that assess demographic population size, genetic diversity, and geographic origins of bats present during resident and migratory periods.

As with acoustic surveys, mist-netting surveys should account for both spatial and temporal variation. Multiple surveys conducted several times across the breeding and migratory seasons will be necessary to answer questions of interest. For example, based on a study in northern California (Weller and Lee 2007), a minimum of three surveys at each of four sites between 1 July and mid-September were needed to adequately characterize a forest bat species assemblage of eight species in that region. Level of effort required to answer different pre-construction questions will vary by species of interest, habitat, time of year, and other factors that should be assessed and factored into decision on whether to employ mist-netting (or using harp traps).

All methods used to capture bats are subject to bias (Kunz and Brock 1975, Kunz and Kurta 1988, O'Shea and Bogan 2003), and inferences from mist-net surveys should be made in the context of these biases. Whereas the influence of capture-related bias is well understood for sampling small mammals (e.g., Chao 1987), the magnitude of this bias remains unclear for bats. Most studies using mist-nets assume similar detection probabilities across sites, but the extent to which this assumption is realistic is unknown (Anderson 2001, MacKenzie 2005, MacKenzie 2006). Temporal patterns of bat activity vary with weather and other factors (Hayes 1997, Erickson and West 2002), yet the effect of these variables on detection probability using mist-net captures as an index of bat abundance has not been fully evaluated. Indices based on mist net capture data should be interpreted with caution until the assumption of constant detection probability is validated (McKelvey and Pearson 2001, O'Shea et al. 2003).

If mist-netting is to be used, optimal results may be obtained by using mist-netting in combination with acoustic monitoring to inventory the species of bats present at a site (Kuenzi and Morrison 1998). If mist-netting is to be used to augment acoustic monitoring data at a project site, trapping efforts should concentrate on potential commuting, foraging, drinking, and roosting sites. Biologists with training in bat identification, equipment use, and data analysis and interpretation should design and conduct all studies discussed below. Mist-netting and other activities that involve capturing and handling bats may require permits from state and/or federal agencies.

***Exit Counts / Roost Searches.*** Pre-permitting survey efforts should include an assessment to determine whether known or likely bat roosts in mines, caves, bridges, buildings, or other potential roost sites could occur near proposed wind-turbine sites. If active roosts are detected during this assessment, exit counts and roost searches can be performed to assess the size, species composition, and activity patterns related to any bat-occupied features near project areas. When bat colonies are relatively small (usually <1,000; Kunz et al. 2009b), visual censusing may be practical and potentially less disturbing to the colony than other methods (Kunz and Anthony 1996, Kunz 2003, Kunz et al. 2009a). Larger colonies will require censusing protocols using thermal infrared imaging cameras that can provide reliable estimates of number of bats present (Frank et al. 2003, Kunz 2003, Betke et al. 2008, 2009), although repeated sampling is required to assess seasonal changes in abundance and colony composition. Rainey (1995) provides a guide to options for exit counts. Roost searches should be performed cautiously because roosting bats are sensitive to human disturbance (Kunz et al. 1996). Known maternity roosts should not be entered or otherwise disturbed. Searches of abandoned mines or caves can be dangerous and should be conducted only by experienced researchers. For mine survey protocol and guidelines for protection of bat roosts, see the appendices in Pierson et al. (1999). Multiple surveys may be required to confirm the presence of specific species of bats in caves and mines (see Sherwin et al. 2003).

***Radar.*** Numerous radar technologies (including NEXRAD Doppler, tracking radar, and marine radar) have been used to estimate the amount of nocturnal activity of volant animals (Kunz et al. 2007). NEXRAD is readily available, but fixed locations limit coverage and the low resolution makes it impossible to distinguish insects from birds or bats since no information is provided on individual targets. NEXRAD cannot provide information on nocturnal activity at or below turbine height, and because of the curvature of the earth the effective coverage overshoots much of the bird migratory movement (NRC 2007) at distances beyond 40 km of the station location. However, it can provide information for assessing larger scale spatial and temporal patterns of flying animals (NRC 2007) and has been used to understand bat dispersal from caves and hibernacula (Horn and Kunz 2008).

Marine radar has commonly been used to estimate nocturnal migrating passerine activity and also has some limited application to the study of bat activity at wind facilities (See Kunz et al. 2007a). Marine (X-band) radar systems were originally designed for use on boats, but commonly have been used as mobile units to estimate the passage rates, flight paths, flight directions and flight altitudes of nocturnal targets. These units typically are mounted on a trailer or vehicle (e.g. van) and are designed to be able to collect data with the antennae in both the horizontal (passage rates, flight paths, flight directions) and vertical (passage rates and flight altitudes) orientation. The units also have been configured to measure flight altitudes with a parabolic dish (Cooper et al. 1991; Gauthreaux 1996). Both 3-cm (X-band) and 10-cm (S-band) marine radars have been used to study bird movements, but no studies have been published comparing effectiveness of each type relative to bird, bat and insect detections. Precipitation and insect contamination can be problematic with X-band radar. S-band radar is less prone to these contaminations but lower detection of smaller bird and bat targets may be an issue. Marine radar by itself cannot distinguish a migrating bird from a bat, and insects cannot always be easily distinguished from bat/bird targets. Simultaneous collection of X-band radar data with acoustics, thermal imaging, and or night vision has been used to help quantify the relative level of bird activity and bat activity within the range of detection and subsequent exposure of birds and bats to wind turbine impacts. However, more research and development is required for the effective application of these tools to quantifying targets by species.

Tracking radar systems can be used to collect information on individual birds, bats and insects, including wing beat signatures to help discriminate these groups (Kunz et al. 2007a). This tool has not been commonly used at proposed wind facilities because it is not generally available, has limited spatial coverage, and can be difficult and expensive to maintain and repair. A review of small radar systems in studying bird movements can be found in Desholm et al. (2004) and MacKinnon (2006). The application of these tools to the study of nocturnal birds and bats is contained in Appendix A.

## SUMMARY

Pre-construction baseline and modeling studies should follow well-designed protocols and common methods and metrics adapted to site characteristics, species of interest, and the speed at which development of specific sites occurs. Protocols, methods and metrics also may be influenced by permit requirements and stakeholder interest. These more in-depth studies will necessarily be focused on those areas of uncertainty identified during screening and site assessment studies.

Pre-construction baseline and modeling studies provide the information that a developer needs to determine if a project is going to be developed, how a site should be developed to avoid or minimize risk, and potential other mitigation measures for unavoidable adverse impacts to wildlife. These studies also provide site-specific and detailed information on the abundance, distribution, behavior, and habitat associations within a site selected for development. The data from these studies must provide the detail required by any permitting process required for the project. These data also provide the pre-construction component of studies that will be continued during post-construction. While the need and protocol for these BA studies should be identified during pre-construction problem formulation, the protocol for these studies also may influence how a project is constructed. For example, if special blade painting is selected as a potential risk-reduction measure that must be evaluated with post-construction studies, the protocol for painting of blades would determine which turbines were treated with the special paint and which turbines were used as controls (i.e., not receiving the special paint). Likewise, if a permit specifies phased development within the context of an adaptive management development process, baseline studies would be designed to provide the pre-construction data on the effectiveness of risk reduction measures so that the design of future phases of the development would be influenced by the outcome of studies of the first phase of development.

## DECISION PROCESS

At the end of pre-construction studies, the developer, and potentially the permitting authority, will make a decision regarding whether and how to develop the project. Development may be delayed or abandoned in favor of sites with less potential for environmental impact or other sites or landscapes may be evaluated in search of more acceptable sites for development. However, if a developer has followed a risk assessment approach as described above and in Appendix B, a decision to abandon a site at this stage of the process is very unlikely. Most likely, the decisions at this point will focus on how to develop a site to avoid, minimize or mitigate the potential effects that have been identified during pre-construction studies.

# CHAPTER 4: POST CONSTRUCTION FATALITY STUDIES

## INTRODUCTION

Post-construction fatality studies focus specifically on estimating the fatality rate and in many cases the total estimated fatalities at an operating wind energy facility. In addition, they are useful for characterizing the species composition of fatalities, potentially identifying factors related to higher mortality (e.g. proximity to features), and for understanding the need for and the success of mitigation in an adaptive management context.

## PROBLEM FORMULATION

Post-construction fatality studies are primarily for estimating the overall fatality rates for birds and bats at a wind facility and involve searching for bird and bat carcasses beneath turbines. The data also may be useful in determining species composition of fatalities, estimating relationships between fatalities and site characteristics, comparing fatality rates among facilities, comparing actual fatality rates with those predicted in pre-construction studies, and determining whether fatality rates warrant additional mitigation measures.

The level of effort and seasonality of studies may vary depending on several factors, including site sensitivity and risk level, amount and quality of existing data from nearby sites, and the species of interest. The questions and methods described here generally assume at least two years of post construction data. However, it may be reasonable to consider one year of monitoring in cases where operating facilities exist near the project area and the fatality data from those projects, as well as other supporting information, strongly support low impacts and/or very high certainty in predicted mortality. For example, numerous fatality monitoring studies have been conducted at projects in agricultural settings in the Columbia Plateau Ecoregion of the Pacific Northwest (see Johnson and Erickson 2008). The results of these studies indicate similar mortality rates and species composition for birds and bats, which were consistent with predicted impacts. Consequently, one year of post-construction monitoring for new projects in this setting would be a reasonable requirement. Notwithstanding, it may be reasonable to consider longer-term monitoring in cases where fatality rates are very high, high uncertainty is observed in the first year, or in order to answer specific questions about levels and cause of mortality over time. These more detailed studies are described in Chapter 5 and generally respond to the need for additional risk reduction, evaluation of additional mitigation measures, or population-level effects of fatalities.

### Objectives Stated Questions

The following are the most important questions that post-construction fatality studies should be designed to answer.

1. What is the bird and bat fatality rate for the project?

The primary objective of fatality searches is to determine the overall estimated fatality rate for birds and bats for the project. These rates serve as the fundamental basis for all comparisons of fatalities, indicators of relationships with site characteristics and environmental variables, and evaluation of mitigation measures implemented at the time of project construction. In the past, fatality rates have been expressed on a per turbine per period basis, per MW nameplate per period basis, per rotor swept area per period basis, and per kWh per period basis. Other metrics may be more appropriate, such as per rotor swept hour per period. Metrics are further discussed below. The level of effort to answer this question will depend on the desired precision of the rate estimates. Typically post-construction fatality studies should be designed such that the desired precision allows the researcher to address the following more specific questions:

A. What is the total number of fatalities of birds and bats?

B. Is the fatality rate low, moderate or high relative to average fatality rate for other projects in similar landscapes or with similar species composition?

C. Is the fatality rate for individual species of such a magnitude that there is concern for biologically significant effects (i.e., population effects, reduced population viability)?

Given the nature of questions A, B, and C, precision to reliably answer these questions might result in coefficients of variation in the range of 20-30%. However, there are situations, such as to meet permit requirements, when a more precise estimate of the level of mortality is necessary. In those cases, significantly more effort would be required to achieve a coefficient of variation less than 20%.

2. What are the fatality rates of those species determined to be of special interest?

This analysis simply involves calculating fatality rates for individual species of interest at a site. Species-specific fatality rates will be most precise for the most commonly killed species.

Estimates of the fatality rates or survival rates of rare species, or for local breeding populations, may require much more intensive study, such as conducting radio-telemetry studies or conducting more intensive fatality searches.

3. How do the estimated fatality rates compare to the predicted fatality rates?

There are a number of ways that predictions can be assigned and later evaluated with actual fatality data. During the planning stages in site assessment studies, predicted fatalities and associated uncertainty may be derived from existing data at similar facilities in the region. Metrics derived from pre-construction assessments for an individual species or group of species, usually an index of activity or abundance and uncertainty, could be compared to estimated post-construction fatality rates. Theoretically it could be assumed that some non-fatality metrics (e.g., number of birds seen per survey) are highly correlated with fatality rates and that these metrics could be used to predict fatalities. For example, Figure 1.4 illustrates the potential correlation between diurnal raptor use during pre-construction surveys and estimated post-construction fatality rates. This particular analysis was limited by the small number of facilities that collected both use and fatality data, which is illustrated by the wide prediction intervals. There will be numerous facilities added to such an analysis in the very near term and this larger sample size should strengthen the analysis. There are collision risk models that use the wind turbine characteristics and potentially numerous other factors (bird characteristics, wind turbine layout, bird abundance) to predict fatalities (e.g., Tucker 1996, Nations and Erickson 2010, Podolsky 2004, Band et al. 2006). These models are especially useful when predicting fatality rates for rare species where empirical fatality data are lacking.

4. How do the fatality rates compare to the fatality rates from existing facilities in similar landscapes with similar species composition and use?

Comparing fatality rates among facilities with similar characteristics is useful to determine patterns and broader landscape relationships. It also helps interpret the significance of the fatalities at the newer facilities, as described under question 1 above. Fatality rates should be expressed as a common metric among facilities. If all the facilities under comparison are using identical turbines then a per-turbine metric may be satisfactory. However, because there is variation in the size of turbines across the country, these comparisons normally should use a standardized metric, such as a per MW or per rotor swept area rate.

5. Do bird and bat fatalities vary within the facility due to some facet of the site characteristics?

The presence or absence of fatalities or counts of fatalities can be compared to site characteristics associated with fatality locations or fatality counts (e.g., distance to features, proximity to water, forest edge, slope, etc.) as well as weather characteristics to determine associations between fatalities and site characteristics. For example, Erickson et al. (2004) compared the fatality rates of nocturnal migrants and bats at lit turbines v. unlit turbines, and detected no significant differences. Associations between fatalities and site characteristics are particularly useful to determine future micro-siting options when planning a facility or, at a broader scale, in determining the location of the entire facility. Additional information can be gained by comparing these relationships among facilities. However, these analyses will have a limited ability to detect minor effects if sample sizes are set to achieve a specified precision on answers to questions 1-4.

6. What is the species composition of fatalities in relation to species composition of migrating and resident birds and bats at the site?

The most simplistic way to address this question is to identify the composition of fatalities based on migratory status. For example, the big brown bat (*Galleria mellonella*) is a non-migratory species, so a fatality could be assumed to have come from the local population of big brown bats. Similarly, the hoary bat and red-eyed vireo (*Vireo olivaceus*) are known to migrate long distances, and if the facility is outside their summer or winter ranges then a fatality could be assumed to have come from a migratory population of these species. However, this simplistic approach fails when a fatality is from a species that resides near the facility and also migrates through the area. Species composition of fatalities may not represent the species composition of actual fatalities because of differences in carcass removal rates, searcher detection rates, and the presence of rare species.

Nevertheless, these data are useful in suggesting patterns of species composition of fatalities and possible mitigation measures directed at either resident populations, migrants, or perhaps both. More detailed investigations using stable isotope and genetic analyses may be conducted to help answer the question of residency status of fatalities.

7. Do fatality data suggest the need for mitigation measures to reduce risk?

Fatality rates that trigger specific mitigation measures are most likely to be identified on a project specific basis as a part of the permitting process or agreement among developers and agencies. For example, the Oregon Department of Energy, with advice from a Technical Advisory Committee made up of multiple stakeholders, developed fatality triggers such that if exceeded, additional mitigation would be considered in lieu of multiple years of additional fatality monitoring (Oregon EFSEC 2009). The basis for defining the fatality rate triggers will almost always be arbitrary and not necessarily based on actual biological effects (e.g. regional population effects) because adequate data seldom exist for defining those effects.

While fatalities estimated during post-construction fatality studies may be used as the basis for requiring additional mitigation, mitigation measures would be evaluated through more detailed study if there was uncertainty about whether the measure would meet the objective of reducing risk of fatalities. NWCC (2007) has developed a mitigation toolbox that identifies potential measures for mitigation at wind projects.

**Field and Analysis Methods for Estimating Fatality Rates**

More detailed descriptions of fatality search protocols can be found in Kunz et al. (2007a), Smallwood (2007) and Huso (2010). Individual states also may have descriptions of fatality search protocols (e.g., California Energy Commission [CEC] and California Department of Fish and Game [CDFG] 2007) and Pennsylvania (Pennsylvania Game Commision [PGC] 2007). Protocols should be standardized to the greatest extent possible, especially for common objectives and species of interest. However, some situations may warrant exceptions to standardized protocols. The following are general guidelines for standardization.

*Fatality Metrics*

Numerous metrics have been used for expressing fatality rates (Smallwood 2007). The more common metrics that have been used include fatalities/turbine/year, fatalities/MW/year, and fatalities/rotor swept area/year. The conventional use of the term MW in this metric refers to the nameplate capacity of the turbine, i.e., the amount of power a turbine would produce if it ran at full capacity. *Rotor swept area* refers to the surface area of the space occupied by a moving rotor. Comparisons of these metrics among sites or turbine types can be drastically different depending on the metric used. Table 4.1 and Figure 4.1 provide an illustration of the different metrics for five different hypothetical projects, each with approximately 100 MW of nameplate capacity (99-100.5 MW) and each using a different turbine type currently in use at wind facilities, and a rotor swept area standardized to 5,000 $m^2$. This illustration places all five projects in the same wind resource area and assumes the bird populations and abundance are the same among the different projects. Also, the bird utilization rates and other risk factors (topography etc.) in this illustration are not different among the sites.

The example developments are:

- 1000 KVS 100-kW wind turbines with 18-m rotor diameters.
- 152 V47 600 kW turbines with 47-m rotor diameters.
- 67 GE 1.5 MW turbines with 72-m rotor diameters.
- 50 V80 2 MW turbines with 80-m rotor diameters.
- 33 V90 3.0 MW turbines with 90-m rotor diameters.

The fatality rates in this example are for illustration purposes only. We assumed that smaller turbines kill more birds on a per MW basis than larger turbines, based on physical collision models (e.g., Tucker 1996) and empirical data from the APWRA (WEST 2008, Insignia 2009). The 100-kW turbines have the lowest per turbine fatality rate (0.5), but have the highest per MW basis and would result in higher overall mortality for the 100 MW project. Comparison of the per turbine fatality rates suggest the largest turbine (V90 3.0 MW) kills the most birds on a per turbine basis, but for an equivalent 100 MW facility, kills the least number of birds (100).

**Table 4.1. Illustration of calculations of different fatality metrics for different sites/turbine types.**

| Turbine Type | MW/ Turbine | # Turbines | Rotor Diameter (m) | Rotor Swept Area/ Turbine | Total RSA 100 MW Project | Fatalities/ Turbine | Fatalities/ 5,000 $m^2$ RSA | Fatalities/ MW | Total Fatalities per 100 MW |
|---|---|---|---|---|---|---|---|---|---|
| KVS | 0.1 | 1,000 | 18 | 254 | 254,469 | 0.5 | 9.84 | 5 | 500 |
| V47 | 0.66 | 152 | 47 | 1735 | 262,870 | 2 | 5.76 | 3.03 | 303 |
| GE 1.5 | 1.5 | 67 | 72 | 4072 | 271,434 | 2.5 | 3.07 | 1.67 | 167 |
| V80 | 2 | 50 | 80 | 5027 | 251,327 | 2.5 | 2.49 | 1.25 | 125 |
| V90 | 3 | 33 | 90 | 6362 | 212,058 | 3 | 2.36 | 1 | 100 |

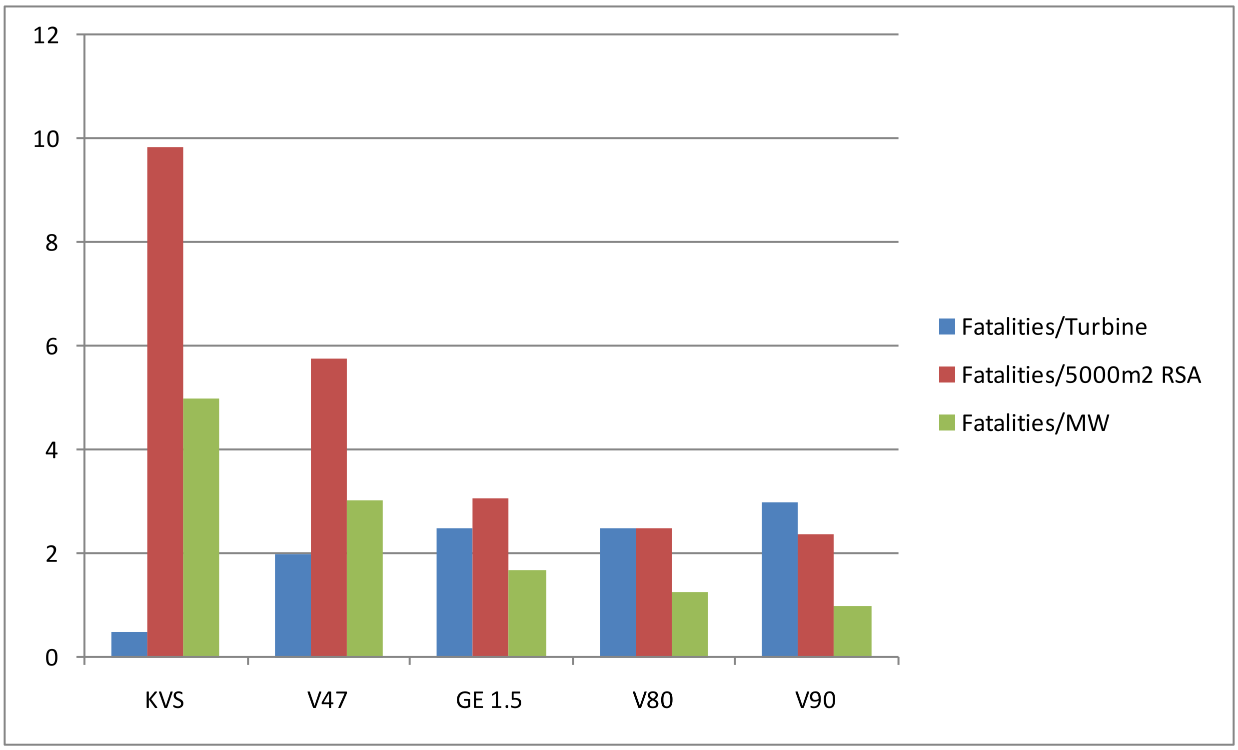


**Figure 4.1. Fatality metrics from the hypothetical data (Table 4.1).**

There are some fundamental differences among turbine brands, even when their nameplate capacity is the same (B. Thresher, NREL, pers. comm.). The previous example illustrates the difficulty of using fatalities per turbine as a metric. Nevertheless, there are limitations with the other two metrics, MW and RSA. Because the MW used in the fatalities per MW metric is the nameplate capacity of the turbine, the use of this metric can be misleading when comparing fatalities among facilities with different wind characteristics. These differences are frequently referred to as a site's capacity factor, i.e., the actual amount of power produced over time divided by the name plate capacity. The rotor swept area can be standardized among sites, as was done in the above example. However, variation in wind characteristics among sites will result in turbines turning more or less often, presumably with less risk of fatalities occurring at sites with a lower capacity factor. Consequently, there is a need for an alternative metric that can be used to compare modern turbines, one that is easily standardized among wind facilities and turbine types. This alternative metric should also incorporate differences in blade size and operation time. The *rotor swept hour* metric proposed by Anderson et al. (1999) would meet these requirements. Rotor swept area is converted to an index that incorporates operation time as follows:

*rotor swept hour* = rotor swept area * operation hours

An index of risk is then calculated by using a measure of risk (e.g., avian or bat use within the rotor swept area):

*rotor swept hour risk* = risk measure/rotor swept hour

While the rotor swept area of different turbines is easily obtained, the use of this alternative metric depends on the availability of the number of hours turbines operate during study periods. We recommend reporting fatalities per name plate capacity of the turbines being studied (i.e., fatalities/MW) until turbine operational data becomes more universally available. We recommend that the wind industry provide operating time information for projects to allow such calculations.

*Estimators of Fatality*

Fatality estimates generally are based on a sample of carcasses detected in plots around wind turbines. However, this alone is an underestimate of actual mortality, since not all casualties are recorded. Fatalities may land outside the searched area or injured animals may move outside the search area before dying and in either case are not available to be found (area bias). Observers may miss carcasses that are in the searched area (detection bias) and casualties that occur between searches may be removed by scavengers prior to the next search (removal bias). The probability of detection can vary by habitat, season, size of specimen, and type of specimen (bird vs. bat). Searcher efficiency may be close to 1 for large birds, such as most raptors and waterfowl; it is often significantly less than 1 for small specimens, such as bats and songbirds. The search interval, or time between searches, coupled with these other factors, affects the uncertainty in the fatality estimates.

The biases associated with carcasses being removed by scavengers and searchers' inability to find all carcasses available for detection has long been recognized. Colvin et al (1988) noted that above-ground carcasses are difficult to locate because of their cryptic coloration and removal by predators. Linz et al. (1991) proposed an approach to correct for these biases by using planted carcasses, trained searchers, and specific search protocols. Morrison (2002) recommended that these biases be estimated and used to correct raw carcass counts during fatality studies associated with wind energy development. Huso (2010) noted that carcasses could be used as an index to fatalities "if there were a direct (linear) relationship between the number of observed carcasses and the number of animals that were killed." However, Huso (2010) also noted that "the relationship is not direct, and counts recorded using different search intervals, in areas with different carcass removal rates and searcher efficiency rates, are not directly comparable."

Numerous approaches have been used to estimate mortality at wind projects (e.g., Orloff and Flannery 1992; Erickson et al. 2000b, 2004; Johnson et al. 2003; Kerns and Kerlinger 2004; Fiedler et al. 2007; Kronner et al. 2007; Smallwood 2007; Huso 2009). All of these estimators attempt to incorporate adjustments for scavenging and searcher efficiency into the estimates. Nevertheless, estimators can be biased by the search interval relative to length of time a carcass remains within a search plot (i.e., carcass removal time).

*Example Estimators*

*We provide the following examples to illustrate commonly used formulas for mortality estimates. We do not include an estimator applied to earlier fatality studies that has recently been termed the "naïve" estimator (Huso2010). It was originally used in studies with long search intervals (Erickson et al. 2001) where bias was relatively small, but has been inappropriately applied in more recent studies (e.g., Fiedler et al. 2007). We provide two cases in the examples, with only average carcass removal rates differing between the two cases. Two differences between these estimators are how both carcass persistence and searcher efficiency are modeled and incorporated into the estimators.*

*The Huso (2010) and Jain (Jain et al. 2009) estimators are based on the assumption that the estimate of p reflects the long-range or total probability of observing a carcass during any search. Because p is often estimated in single day trials, the simple estimate of probability of detection after a single search is used in the Huso and the Jain estimator.*

*The Huso and Jain estimators have been derived based on the assumption that a carcass that is missed by searchers once, do not have a chance of being picked up again. The Shoenfeld estimator is generally based on the assumption that the observers have the ability to find carcasses in subsequent search attempts, if they are missed during the first search, but that the search detection rate doesn't change over time.*

Example 1: Longer average carcass removal time.

*Assume*

*Total length of study = 365 days*

$\bar{c} = 2$ *= total number of carcasses per turbine for the sampling period*

$\bar{t}$ *= average carcass removal time = true average whenever there are no censored observations (no data removed from the analysis) = 10.4 days*

*I = average search interval = 7 days*

$P_{det}$ *= probability of observer detection given that the carcass remains = 0.5*

*A = proportion of area searched for each turbine = 1*

*Resulting values*

$\hat{\pi} =$ *probability of carcass availability and detection*

*M = adjusted fatality estimate*

$\tilde{I} =$ *effective interval, used in Huso's method*

$\hat{s} =$ *effective proportion of the interval sampled, used in Huso's method*

$\hat{r} =$ *estimated probability of carcass availability, used in Huso's method*

**Shoenfeld's Estimator** (Shoenfeld 2004)**:**

$$\hat{\pi} = \frac{Tbar * Pdet}{I}\left(\frac{exp\left(\frac{I}{Tbar}\right) - 1}{exp\left(\frac{I}{Tbar}\right) - 1 + Pdet}\right)$$

$$M = A * \frac{\bar{c}}{\hat{\pi}}$$

For our example:

$$\hat{\pi} = \frac{10.4 * 0.5}{7}\left(\frac{exp\left(\frac{7}{10.4}\right) - 1}{exp\left(\frac{7}{10.4}\right) - 1 + 0.5}\right) = 0.4885$$

$$M = 1 * \frac{2}{0.4885} = \boxed{4.09}$$

**Huso's Estimator (Huso 2010):**

$$\tilde{I} = -\log(0.01) * \bar{t}$$

$$\hat{s} = min\left(1, \frac{\tilde{I}}{I}\right)$$

$$\hat{r} = \frac{\bar{t} * \left(1 - e^{-\frac{I}{\bar{t}}}\right)}{I}$$

$$\hat{\pi} = P_{det} * \hat{s} * \hat{r}$$

For our example:

$$\tilde{I} = -\log(0.01) * 10.4 = 47.9$$

$$\hat{s} = min\left(1, \frac{47.9}{7}\right) = 1$$

$$\hat{r} = \frac{10.4 * \left(1 - e^{-\frac{7}{(10.4)}}\right)}{7} = 0.7278$$

$$\hat{\pi} = 0.5 * 1 * 0.7278 = 0.3639$$

$$M = \frac{2}{0.3639} = \boxed{5.50}$$

**Orloff and Flannery (1992) and Jain's Estimator (Jain et al. 2009):**

$S_c$ = the proportion not scavenged = 0.45 after 7 days estimated from a carcass removal experiment

$$M = \frac{\bar{c}}{S_c * P_{det}} = \frac{2}{0.45 * 0.5} = \boxed{8.89}$$

Example 2: Shorter average carcass removal time.

Assume

Total length of study = 365 days

$\bar{c} = 2$ = total number of carcasses per turbine for the sampling period

$\bar{t}$ = average carcass removal time = true average whenever there are no censored observations (no data removed from the analysis) = 4 days

$I$ = average search interval = 7 days

$P_{det}$ = probability of observer detection given that the carcass remains = 0.5

A = proportion of area searched for each turbine = 1

Resulting values

$\hat{\pi}$ = probability of carcass availability and detection

$M$ = adjusted fatality estimate

$\tilde{I}$ = effective interval, used in Huso's method

$\hat{s}$ = effective proportion of the interval sampled, used in Huso's method

$\hat{r}$ = estimated probability of carcass availability, used in Huso's method

$$M = \frac{2 * 7}{10.4 * 0.5} = \boxed{2.69}$$

**Shoenfeld's Estimator:**

$$\hat{\pi} = \frac{\bar{t} * P_{det}}{I}\left(\frac{exp\left(\frac{I}{\bar{t}}\right) - 1}{exp\left(\frac{I}{\bar{t}}\right) - 1 + P_{det}}\right)$$

$$M = A * \frac{\bar{c}}{\hat{\pi}}$$

For our example:

$$\hat{\pi} = \frac{4 * 0.5}{7}\left(\frac{exp\left(\frac{7}{4}\right) - 1}{exp\left(\frac{7}{4}\right) - 1 + 0.5}\right) = 0.2585$$

$$M = 1 * \frac{2}{0.2585} = \boxed{7.74}$$

**Huso's Estimator:**

$$\tilde{I} = -\log(0.01) * \bar{t}$$

$$\hat{s} = min\left(1, \frac{\tilde{I}}{I}\right)$$

$$\hat{r} = \frac{\bar{t} * \left(1 - e^{-\frac{I}{\bar{t}}}\right)}{I}$$

$$\hat{\pi} = P_{det} * \hat{s} * \hat{r}$$

$$\hat{\pi} = P_{det} * \hat{s} * \hat{r}$$

For our example:

$$\tilde{I} = -\log(0.01) * 4 = 36.8$$

$$\hat{s} = min\left(1, \frac{36.8}{7}\right) = 1$$

$$\hat{r} = \frac{4 * \left(1 - e^{-\frac{7}{4}}\right)}{7} = 0.4721$$

$$\hat{\pi} = 0.5 * 1 * 0.4721 = 0.2361$$

$$M = \frac{2}{0.2361} = \boxed{8.47}$$

**Orloff and Flannery and Jain's Estimator:**

$S_c$ = the proportion not scavenged = 0.14 after 7 days in our example

$$M = \frac{\bar{c}}{S_c * P_{det}} = \frac{2}{0.14 * 0.5} = \boxed{28.57}$$

*Selection of Estimator*

The estimators in all these examples have assumed that the probability of detection of 0.5 is for one search. In an actual study multiple searches of a plot would occur. The Shoenfeld estimator (Shoenfeld 2004) generally assumes that search efficiency is constant over time, and that a carcass that is missed on one search has the same probability of detection for subsequent searches. This assumption of constant search efficiency may result in biased estimates if the actual searcher efficiency varies over time (e.g., decreases over time, increases then decreases over time). The searcher detection rate used in the example of the Huso estimator (Huso 2010) is for a one-time search, and under this assumption a carcass missed on the first search has no possibility of detection on subsequent searches. However, many of the carcasses could be available for a second search or more in the example, because the mean removal time is greater than the search interval. Limiting the possibility of detection to one search would overestimate y. An adjustment can be made in the Huso design to address this shortcoming. Instead of using *p* from a single search, carcasses could be left in the field over multiple searches to determine searcher efficiency over these multiple searches. If this design is used, the Huso estimator (Huso 2010) would be recommended. Nevertheless, this design requires more effort for the searcher efficiency trials than using *p* from a single search or assuming constant searcher efficiency as with the Shoenfeld estimator (Shoenfeld 2004). When searcher efficiency is very low (e.g. 10%) or very high (e.g. 90%) and carcass removal is very low or very high compared to search interval, the estimators can provide very different results. In the case of very low detection and high carcass removal relative to search interval, the Huso estimator appears to be the most accurate (least biased); however, the estimates produced by any of the estimators will be extremely imprecise and not very useful in the case of low detection. In the case of high searcher efficiency and low carcass removal relative to the search interval, the estimators may differ greatly due to the dependence on assumptions regarding searcher efficiency over time. More research into the robustness and properties of these estimators for use in fatality studies is needed.

Fatality studies should be designed so that the average carcass removal time is longer than the average search interval, in which case either the Shoenfeld or Huso estimators may be used. However, when that is not possible, different estimators should be used depending on whether the average carcass removal time is longer or shorter than the average search interval. When removal time is less than the search interval, we recommend that the Shoenfeld (2004) or Huso estimator (Huso 2010) be used. When the removal time is greater than the search interval, the Shoenfeld estimator may underestimate and the Huso estimator may overestimate fatalities depending on the assumptions related to searcher efficiency over time. The Huso estimator may have less bias if it is modified so that searcher detection rate is for multiple searches as discussed above. Given that there is no perfect estimator, we recommend that fatalities be calculated using more than one estimator and if the fatality estimates are very different, then investigate the reasons for the difference.

There are other potential biases that have not been discussed and that may influence fatality estimates, such as background mortality (e.g., Johnson et al. 2000a), type of carcass used and methods for conduct of searcher efficiency and carcass removal trials (Smallwood 2007, Erickson 2007), and plot size (Kerns et al. 2005). These biases can be either negative or positive depending on the circumstance. For example, background mortality at the Buffalo Ridge facility in Minnesota was estimated to be approximately one third the total mortality estimated within the wind facility (Johnson et al. 2000a). Waterfowl and rock doves (*Columba livia*) are often used to represent large and medium raptors. At the APWRA in California, waterfowl scavenging rates were much higher than for large raptors (Altamont Pass Monitoring Team 2008). Alternatively, once frozen but thawed bat carcasses had a lower scavenging rate than fresh bat carcasses (Kerns et al. 2005).

*Duration and Frequency of Monitoring*

Duration and frequency of fatality searches will vary depending on a number of factors, most notably the species of interest, seasons of interest, and carcass removal rates. Search interval is the interval between searches of individual turbines, and these intervals have varied from 1-90 days. As long as standard search methods (we suggest line transect sampling) are employed and sampling biases (search efficiency and scavenger removal) are adequately accounted for, results from studies with 1-30 day search intervals should be reasonably comparable when grouped into low, moderate or high categories. However, some estimators that have been used have been severely biased, depending on the values of searcher efficiency and scavenging, rendering findings incomparable. If the primary objective of fatality searches is raptor fatalities, carcass removal rates are low and searcher efficiency is high, then longer intervals between searches are acceptable. Longer search intervals (e.g., 30 days) have generally been used in the APWRA, where raptor mortality has been the focus (Smallwood and Thelander 2008, Altamont Pass Monitoring Team 2008). These intervals have lead to reasonably precise estimates for large raptors like golden eagles and red-tailed hawks. Estimates for burrowing owls and American kestrels are relatively imprecise, however, for a variety of reasons, including the higher carcass removal rates for these small raptors, lower searcher efficiency estimates compared to larger raptors, and in the case of burrowing owls, some more uncertainty as to the cause of death for some fatalities (ICF Jones & Stokes 2009). In a detailed study of burrowing owl and American kestrel mortality, very few fatality detections were intact carcasses with evidence suggesting wind turbines caused the death. One of the possible explanations was that some of the carcasses detected were due to predation rather than turbine collision, and therefore intact carcasses never were available for detection.

We recommend a search interval of 7 days in most cases to answer post-construction fatality questions, and protocols should be designed such that some turbines are sampled most days each week of the study. Notwithstanding, larger or smaller search intervals may be justified. If, for example, the primary objective is fatalities of large raptors and carcass removal is low, then a longer interval between searches (e.g., 14-28 days) may be sufficient. However, if the focus is fatalities of bats and small birds and carcass removal is high, then a search interval of < 7 days will be necessary. For example, if the mean removal rate established by carcass removal trials is 2 days, then the search interval should be no more than 4 days. If, however, bats and small bird mortality is the primary objective, in areas where carcass removal is high and/or searcher efficiency is low (e.g., <25%), then shorter search intervals are necessary to achieve reasonably precise estimates.

*Illustration*

The effort necessary to search a turbine for carcasses depends on numerous factors, including size of the plot, spacing of transects, vegetative cover, slope, walking speed, level of mortality etc. While each project will vary, we illustrate this effort in the following example (Table 4.2). We assume square plots 80, 160, and 240 m on a side (minimum of 40, 80 and 120 m from turbine). The 80x80 m plot is 1.56 acres, the 160 x 160 m plot is 6.3 acres, and the 240x240 m plot is 14.2 acres in size. If we assume transects are approximately 6 m apart, and technicians work at approximately 35 m/minute, it would take approximately 0.59 hr, 2.12 hr and 4.65 hr to search the three different sized plots. Additional field time not considered in these estimates includes travel time to the site, travel time between sites, coordination, and conduct of experimental trials. Given the above factors in our example, conducting daily searches at a 10-turbine site with the moderate size plots would take a crew of 3-5 people.

**Table 4.2. Illustration of estimated search time required for different sized plots.**

| Plot Size | Hectares | Acres | Time to Search |
|---|---|---|---|
| 80x80m | 0.64 | 1.58 | 0.59 |
| 160x160m | 2.56 | 6.33 | 2.12 |
| 240x240m | 5.76 | 14.23 | 4.65 |

*Number of Turbines to Monitor*

The number of turbines to sample depends on the objectives of the studies, the spatial variation in fatality rates among turbines, and other characteristics of the site. As a general rule we recommend that approximately 30% of the turbines in the project area should be selected randomly or via a systematic random sample for searching. If the project contains less than 30 turbines, we recommend searching at least 10 turbines in the project area, unless otherwise agreed to by the regulating agencies.

*Plot Size*

Evidence suggests that >80% of bat fatalities fall within ½ the maximum distance of turbine height to ground (Erickson et al. 2003a, 2003b), and a minimum plot radius of 50 m from the turbine should be established at sample turbines if the focus is estimating bat fatality rates. However, larger plots are necessary for birds, which tend to be found farther from turbines (e.g., Johnson et al. 2003; Kerlinger et al. 2006; TRC Environmental Corporation 2008; Stantec Consulting Inc. [Stantec] 2009; Young et al. 2007, 2009). Figure 4.2 shows data for birds and bats at the Nine Canyon Wind facility in eastern Washington. Approximately 95% of the bat fatalities were observed within search plots (Erickson et al. 2003b).

Figure 4.3 illustrates the distribution of bird carcasses determined during fatality studies at the Stateline Wind Energy Project (Erickson et al. 2003a). We recommend that search plots for birds have approximately the radius of the maximum distance from the ground to the highest point on the rotor swept area (~ 90-120 m).

Searchable areas vary and often do not allow surveys to consistently extend to the maximum plot radius, especially in forested environments. In this case, the searchable area of each turbine can be delineated and mapped to adjust fatality estimates based on the actual area searched. We recommend that when making these adjustments visibility classes should be established in each plot to account for differential detectability; no fewer than two (e.g., easy visibility class plus at least one other to describe visibility off concrete pads and roads) and no more than four visibility classes should be used (e.g., PGC 2007). The following visibility classes, modified from PGC (2007), represent reasonable visibility classes that could be used at any project:

Class 1 (easy): Bare ground 90% or greater; all ground cover sparse and 6 inches or less in height (i.e., gravel pad or dirt road).

Class 2 (moderate): Bare ground 25% or greater; all ground cover 6 inches or less in height and mostly sparse.

Class 3 (difficult): Bare ground 25% or less; 25% or less of ground cover over 12 inches in height.

Class 4 (very difficult): Little or no bare ground; more than 25% of ground cover over 12 inches in height.

GPS units are useful for accurately mapping the total area searched and area searched in each habitat visibility class. Transect width for transects used in searches will vary depending on the habitat and species of interest; the key is to determine actual searched area and area searched in each visibility class regardless of transect width (Kerns et al. 2005).

Different approaches have been used to orient plots and transects. Figure 4.4 illustrates orientation of transects in a north-south and circular manner 10 m apart. In the Nine Canyon study (Erickson et al. 2003b), for example, the plots were oriented such that the largest distance searched away from turbines was in the northeast direction, which in that case was the direction of the prevailing winds.

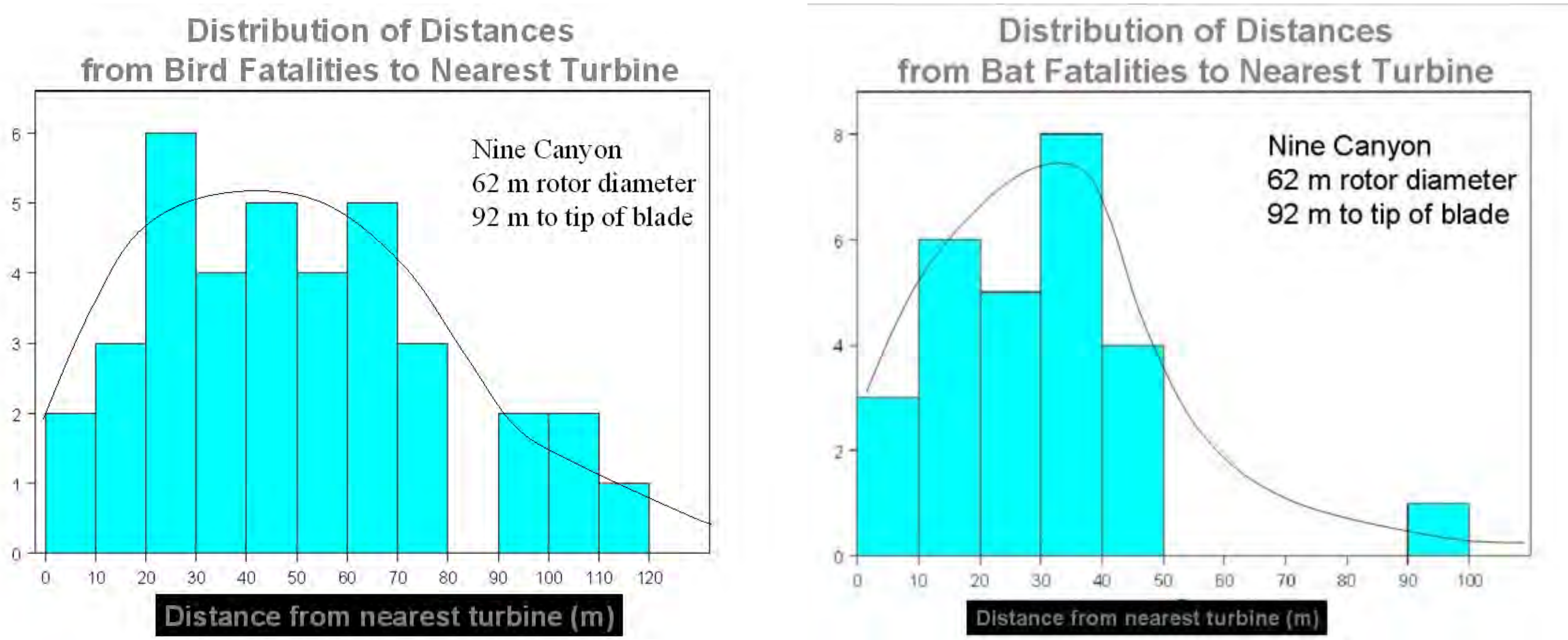


**Figure 4.2. Illustration of the distribution of fatalities as a function of distance from turbines for birds and bats at the Nine Canyon wind energy facility (Erickson et al. 2003b).**

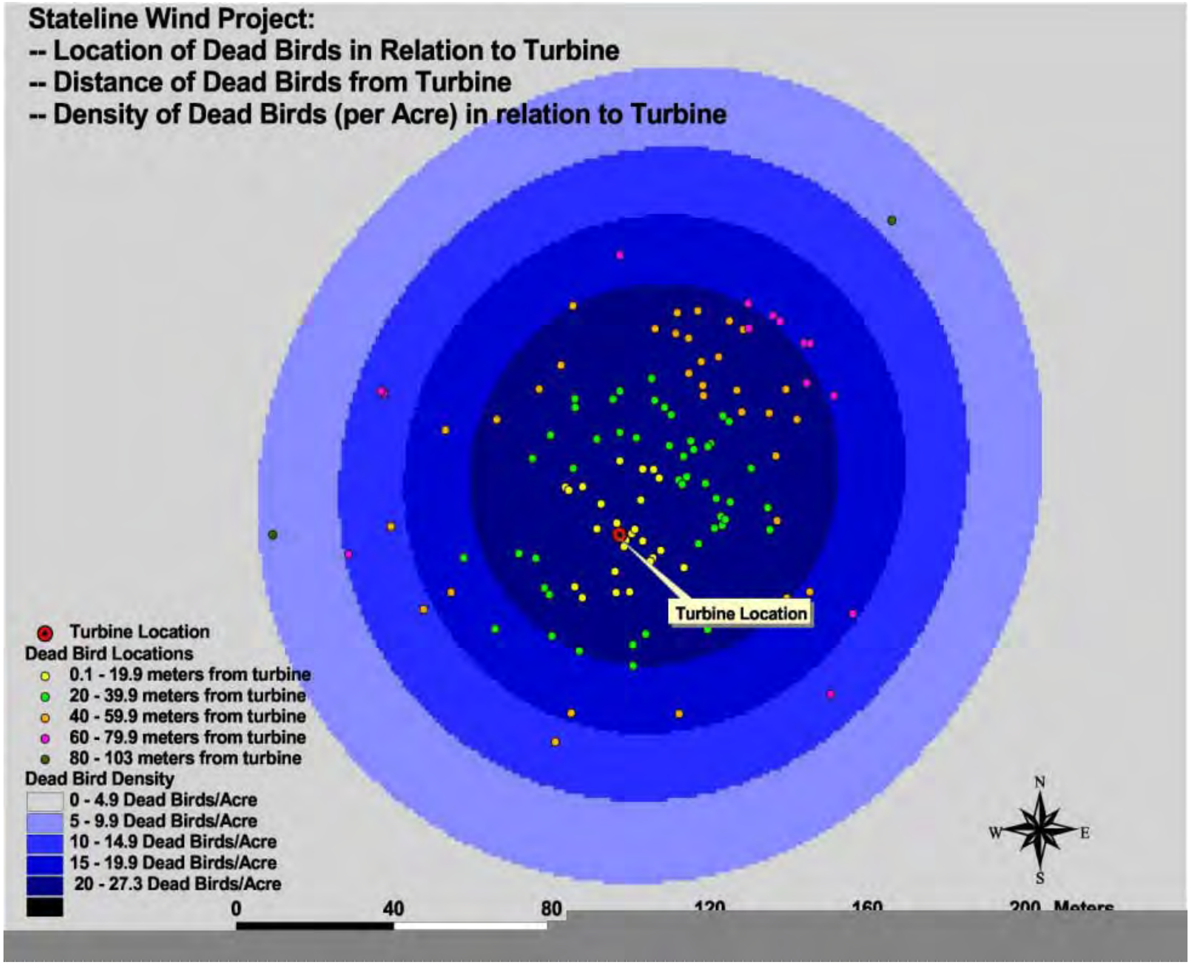


**Figure 4.3. Illustration of the differences in density of bird fatalities as a function of distance from turbines at the Stateline Wind Project. This illustrates higher density of bird fatalities within the first 40 m (Erickson et al. 2004).**

*General Search Protocol Guide*

The following section describes a general protocol for conducting fatality searches at wind energy facilities.

Trained searchers should look for bird and bat carcasses along transects within each plot and record and collect all carcasses located in the searchable areas. Data to be recorded for each search should include date, start time, end time, observer, and weather. When a dead bat or bird is found, the searcher should place a flag near the carcass and continue the search. After searching the entire plot, the searcher returns to each carcass and records information on a fatality data sheet, including date, species, sex, age (when possible), observer name, turbine number, perpendicular distance from the transect line to the carcass, distance from turbine, azimuth from turbine, habitat surrounding carcass, condition of carcass (entire, partial, scavenged), and estimated time of death (e.g., $\leq$1 day, 2 days).

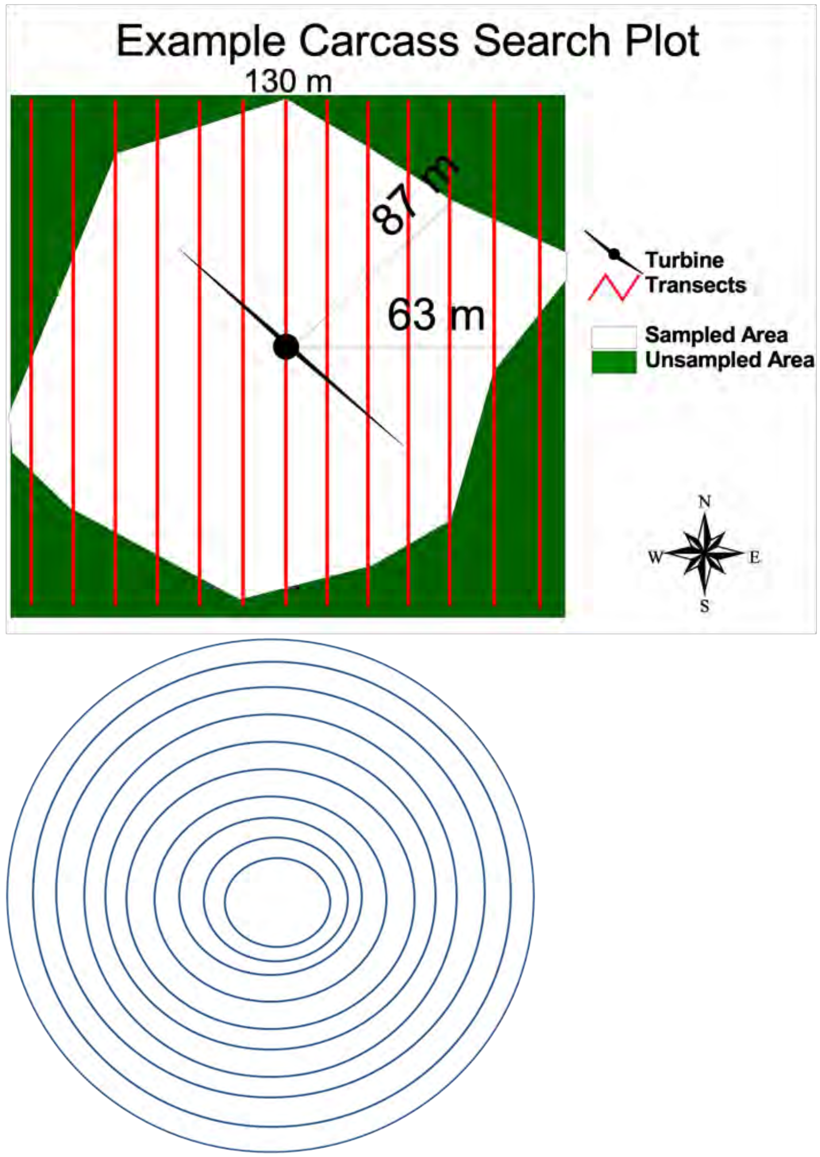


**Figure 4.4. Square plot and circular plots.**

Determining time of death is subjective and will likely vary with the type of organism (bat, small bird, large bird) and the prevailing climate at the study site. A standardized protocol for determining time of death should be developed for each area and included in the overall study protocol. For example, sample carcasses can be placed in the field in a manner that prevents scavenging (e.g., covered by wire cage) to train observers on deterioration with carcass age. However, accurate assessment of the time of death (e.g., to the nearest day) is difficult, especially if carcasses have been scavenged but not removed. The appropriate state and federal permits should be in hand before carcasses are collected. Rubber gloves should be used to handle all carcasses to reduce possible human scent bias for carcasses later used in scavenger removal trials. Carcasses should be placed in a plastic bag and labeled. Fresh carcasses, those determined to have been killed the night immediately before a search, should be uniquely marked and left at their location and/or redistributed at random points to achieve needed sample size by (for example) visibility class.

*Field Bias Assessment*

The number of fatalities picked up by observers and caused by wind turbines is a minimum estimate of the actual number of fatalities killed by the wind facility (Huso 2010). Searchers miss carcasses during searches and scavengers may remove carcasses prior to searches being conducted (Morrison 2002). In addition to the carcass removal and searcher efficiency biases, dead or injured birds and bats may land or move outside search plots.

*Searcher Efficiency and Carcass Removal/Carcass Persistence*

Searcher efficiency and carcass removal/carcass persistence interact to influence the fatality estimates and, unlike search interval, are difficult to control. Consequently it is difficult to establish the minimum searcher efficiency necessary to produce useful fatality estimates.

Both searcher efficiency and carcass removal/carcass persistence parameters can be estimated using carcasses placed in the area by investigators. For estimating carcass removal/carcass persistence parameters (e.g., mean removal time or proportion of carcasses removed one day after placement), carcasses are placed in known, randomly located sites within the study area. The location where the carcass was placed is then revisited daily or at some other interval established by the study protocol (e.g. every other day), and the presence or absence of the carcass is noted. An average persistence time is calculated and from this, the proportion of carcasses remaining at the site over time is determined. For estimating searcher efficiency, an individual not involved in searches places uniquely but cryptically marked carcasses in known locations at sites being searched for the monitoring program. Subsequently, individuals searching for actual carcasses as part of the monitoring effort and who are completely unaware of the carcass locations note when they locate a placed carcass. The average proportion of carcasses found by observers is then determined. Once located by searchers, the same carcasses may be used for estimating scavenging rate and searcher efficiency.

We recommend that estimates for searcher efficiency and carcass removal/persistence be made separately for small birds, medium birds, large birds, and bats, because detectability and scavenging rates likely differ significantly among these groups. To reduce bias due to temporal changes in searcher efficiency and carcass removal/persistence, estimates of carcass removal and searcher efficiency should be replicated over the time for which mortality estimates are made.

Confidence in estimates of searcher efficiency and carcass removal/persistence is a function of the variance in removal and detection rates among searches and is strongly influenced by the number of carcasses used in estimating these values. Estimates derived from low to moderate sample sizes may be highly biased, and thus introduce large errors into mortality estimates. We recommend bias estimation studies, when practical, using a minimum of 50 carcasses for each combination of time period, vegetation type and category of carcass for which a separate estimate of scavenging rate and searcher efficiency is needed.

Low searcher efficiency can lead to highly uncertain estimates, particularly when carcass persistence is low. We recommend efforts be taken to increase searcher efficiency to >25% for small birds and bats, as uncertainty in fatality estimates will decrease as searcher efficiency improves. Searcher efficiency can and should be improved through selection of competent and careful personnel for search teams and training of search crews. Extremely difficult areas to search where detection is likely very low should be eliminated from consideration as they add a large amount of uncertainty in the estimates. Nevertheless, the lack of sampling in those areas needs to be considered when adjusting for sampled area.

Searcher efficiency also can be improved by modifying vegetation through use of herbicides, mowing, or fire to increase detectability of carcasses. For example, in cases where searcher efficiency is extremely low (e.g., complex vegetation) or virtually zero (thick standing crops), elimination of the site from the monitoring program or modification of the site to increase searcher efficiency may be necessary. However, by selecting locations based on habitat characteristics or by altering vegetation to increase searcher efficiency, potential biases can be introduced into the monitoring data if fatalities at turbines that are “easy to search” or that have been subject to vegetation modification differ from other sites. These potential effects should be considered before using such tools.

All fatality studies should include an assessment of carcass removal and searcher efficiency rates during all seasons and under all conditions potentially influencing those rates. Searchers should never be aware which turbines are to be used or the number of carcasses placed beneath those turbines during searcher efficiency trials. Prior to a study’s inception, a list of random turbine numbers and random azimuths and distances (m) from turbines should be generated for placement of each specimen used in bias trials. Data recorded for each trial carcass prior to placement should include date of placement, species, turbine number, distance and direction from turbine, and potentially a measure of visibility detection class surrounding the carcass if visibility varies significantly among plots and/or seasons. Some researchers have suggested trial carcasses should be distributed as equally as possible among the different visibility classes throughout the study period. No studies have suggested a more optimal design; however, given that lower searcher detection rates lead to more uncertainty in estimates, higher sample sizes for searcher efficiency in low visibility classes is probably warranted. In addition, higher sample sizes for small carcasses (e.g., small birds and bats), which tend to have lower detection rates, are reasonable.

Concerns have been expressed over the possible “over-seeding” of the study area so that scavengers are attracted increasing the rate of carcass removal from study plots (Smallwood 2007). Given that multiple carcasses are seldom found at a single turbine (NRC 2007), studies should attempt to avoid “over-seeding” by placing no more than 2 carcasses at any one time at a given turbine. Before placement, each carcass must be uniquely marked in a manner that does not cause additional attraction. There is no agreed upon sample size for bias trials. Huso (2010) suggested 50 carcasses per individual parameter estimated (e.g., carcass removal rates). Most researchers agree that sample size of carcasses used for bias trials should be maximized to the greatest extent practicable.

Other sampling methods that could be considered include line transect sampling where distance from transect line is used to estimate detection probability, double sampling, and ratio estimation. With distance sampling, distance is measured from the transect lines to the fatalities, and used to estimate detection probability with the assumption that detection decreases with distance from the line, and that all objects on the line are detected with a probability of 1 (Buckland et al. 1993). Objects are recorded on either side of the line according to some rule of inclusion. When a total count of objects is attempted within a fixed distance of the line, transect sampling is analogous to sampling on a fixed plot (Conroy et al. 1988). When an incomplete count is assumed, the probability of detecting an object at a perpendicular distance (the detection function) from the transect line is used in correcting for counted objects for visibility bias away from the line (Morrison et al. 2008). Detection functions can be made up of a mixture of more simple functions which depend on factors such as weather, observer training, vegetation type, etc., so long as all such functions satisfy the condition that probability of detection is 100% at the origin $x = 0$ (Burnham et al. 1980). For a more detailed description of strip and line transect please refer to (Appendix B) of this document.

Methods also are available for cases when detection probability is not 1 on the line, but can be estimated. In crop land areas where a sample of plots are cleared, the ratio of fatalities found on the entire clear plot to those found on only pads and roads may be used to correct for a less intensive sample of searches only on roads and pads. The effectiveness and applicability of these and other methods should be tested.

*Use of Dogs to Recover Fatalities at Wind Energy Facilities*

Wildlife biologists increasingly have used dogs in their investigations (Gutzwiller 1990, Shivik 2002). The olfactory capabilities of dogs could greatly improve the efficiency of carcass searches, particularly in dense vegetation (Homan et al. 2001). Dogs generally have been used in research on waterfowl and upland game birds (Zwickel 1980, Gutzwiller 1990), but more recently to recover passerine fatalities during carcass searches (Homan et al. 2001).

Arnett (2006) used Labrador retrievers to assess the ability of dog-handler teams to recover dead bats during fatality searches typically performed at wind energy facilities. He conducted this study at the Mountaineer and Meyersdale Wind Energy Centers in West Virginia and Pennsylvania, respectively. Arnett (2006) trained dogs using fundamental principles employed to teach basic obedience, “quartering” (i.e., systematically searching back and forth in a defined area; 10 m wide belt transects for this study), and blind retrieve handling skills (e.g., Dobbs et al. 1993). He trained these dogs to locate dead bats for 7 days prior to initiating formal field testing by seeding a 10 m wide by 25 m long belt transect with bat carcasses representing different species and in varying stages of decay. When a test bat was found by a dog, it was rewarded with a food treat if it performed the task of locating a trial bat, sitting or at least stopping movement when given a whistle command to do so, and leaving the carcass undisturbed. The decision to begin formal testing of dogs is somewhat subjective, but should be based on the dogs’ quickening response to the scent of trial bats, their response to handler commands, and when they consistently find all trial bats.

Arnett (2006) reported that dogs found 71% of bats used during searcher efficiency trials at Mountaineer and 81% of those at Meyersdale, compared to 42% and 14% for human searchers, respectively. Dogs and humans both found a high proportion of trial bats within 10 m of the turbine, usually on open ground (88 and 75%, respectively). During a 6-day fatality search trial at five turbines at Meyersdale, Arnett (2006) found the dog-handler teams discovered 45 bat carcasses, of which only 19 (42%) were found during the same period by humans. In both trials, humans found fewer carcasses as vegetation height and density increased while dog-handler teams search efficiency remained high. However, in another study (Kronner et al. 2008), the use of dogs in searching for carcasses did not improve searcher efficiency over humans and in fact was less for some of the comparisons. It was suggested that condition of carcass (old versus fresh, wet versus dry) may have influenced this difference.

The use of dogs presents unique challenges that warrant further consideration. Gutzwiller (1990) noted that the use of dogs can alter established protocols and introduce unknown biases relative to traditional human searches. Additionally, Gutzwiller (1990) pointed out that inconsistent performance by different dogs may be attributable to different habitats, weather, and changing physical or physiological conditions for the dog, or any combination of these factors. It is also possible that variability in scent characteristics of bat species being sought and differences in the innate ability of individual dogs may also introduce a bias, but this has not been evaluated. While biases cannot be totally avoided during field research, careful study design and analyses are important for limiting bias (Gutzwiller 1990, Arnett 2006).

*Search Area Corrections*

In many cases, plots are not completely sampled because vegetation, steep slopes or other factors result in areas that are too difficult or too dangerous to search. If entire plots are not searched, corrections for the unsampled area are required. Because the location of carcasses isn't random with respect to turbines, methods other than corrections based on percent of unsampled area should be used. Some different methods have been employed to adjust for unsampled area. Kerns et al. (2005) plotted the density of carcasses in 10 m bands and obtained an overall adjustment to mortality based on the unadjusted estimates. In this particular example, Arnett et al. (2008) modeled the density of carcasses as a function of distance from turbines, but used only fatalities found in high visibility classes to minimize the confounding effect of searcher detection differences.

*GIS Methods for Bat Kill Analysis at Wind Turbines*

*<u>Introduction</u>*

Geographic Information Systems (GIS) technology and methods can be used to more accurately estimate the amount of area surveyed in fatality studies. For example, field technicians could map the extent of several visibility classes in search plots. As described above, the mapped visibility classes divide the search plot into search subplots based on the relative difficulty of finding dead birds or bats (e.g., from "easy" to "very difficult") on the ground during searches. GIS is used to help normalize the actual number of bats found in relation to the expected number of bats based on the area of the search classes at each turbine. Transect width will vary depending on the habitat and species of interest.

The actual area surveyed within a plot will differ among turbines due to different designs (e.g. sizes of search plots, number of turbines searched, etc.), different patterns of vegetation at each turbine in which searching is extremely difficult, and/or occurrence of hazardous features preventing searching all together. The key is to determine actual searched area and area searched in each visibility class regardless of specific protocol being used in the search. The distribution of carcasses within visibility classes also is important. For example, the density of carcasses is known to diminish with increasing distance from the turbine (e.g., Kerns et al. 2005); a simple adjustment to fatality based on proportion of plot area surveyed would likely lead to over estimates. This is because, in heavily vegetated landscapes, unsearched areas tend to be farthest from turbines, and these areas are relatively less affected by the turbine and associated infrastructure. Thus, estimates of fatality should be based on the estimated proportion of total fatalities that occurred in the searched areas, not the proportion of area searched.

The estimated proportion of total fatalities represented by found carcasses can be obtained by modeling the relationship of carcass density to distance from a turbine by using only carcasses with an equal probability of being observed, i.e. those in areas in which searcher efficiency and carcass persistence are constant. The areas that usually provide the largest sample are the Easy visibility class areas. If it can be assumed that the relative density as a function of distance would be the same for all turbines, then carcass locations from all turbines can be combined. This assumption does not require the density of fatality to be the same at all turbines, only that the relative density or the relationship of density to distance should be the same. The relative density of carcasses can be calculated by creating a series of buffers at 2-m increments starting at the edge of the base of the turbine. The density of fatalities within the Easy visibility class at a certain distance from the turbine can be calculated by comparing the number of fatalities found within the Easy class with the area of the Easy class at each 2-m increment. A non-linear function relating fatality density to distance from a turbine (e.g. a segmented cubic polynomial/negative exponential whose value approaches 0 as distance becomes large) should be fit, and from this function density for each square meter in the entire site can be calculated. This number is proportioned over the entire site and a "density-weighted" fraction of each plot that was actually searched is used as an area adjustment to per-turbine fatality estimates.

## SUMMARY

Estimates of bird and bat fatalities are the most common post-construction studies conducted at wind energy facilities and have contributed a great deal to the understanding of the direct impacts of wind energy facilities. Unfortunately, many of the studies have been conducted using non-standard protocols and/or inappropriate estimators. Post construction estimates of fatalities should be designed in consideration of the species most likely to be killed and the land use and vegetation surrounding the facility. Estimation of fatalities will require a minimum of one year, and two or more years of post-construction monitoring when little is known about fatality rates in a particular landscape. Fatality studies should occur over all seasons of occupancy for the species of interest. All fatality studies should include estimates of carcass removal and carcass detection rates for all seasons and all conditions likely to influence those rates. Search plots should be large enough to reduce the likelihood that carcasses will fall outside of the area searched. We recommend at least a 50-m radius plot for bats and a plot with a radius approximately equal to the distance from the base of the turbine to maximum height of the rotor swept area for birds. Not all plots are completely searchable and fatality estimates should be adjusted to correct for the actual area searched. Metrics are very important when comparing fatality rates among turbines and facilities. However, there are a number of complicating factors when making fatality comparisons. First, not all turbines operating at wind facilities are identical. Secondly, the wind characteristics differ within and among facilities. Finally, avian and bat abundance varies within and among facilities. As a general rule, we recommend reporting fatalities per name plate capacity of the turbines being studied (i.e., fatalities/MW). However, if the amount of time a turbine rotates during the study period is known, a more accurate comparison among turbines and facilities would be fatalities per rotor swept hour. If all turbines are identical within a facility, then the metric of fatalities per turbine is adequate for comparisons among turbines within the facility. The selection of the proper mathematical estimator is vitally important. Ideally, studies should be designed so that the average carcass removal time is longer than the average search interval. However, when that is not possible, different estimators should be used depending on whether the average carcass removal time is longer or shorter than the average search interval. When removal time is less than the search interval, we recommend that the Shoenfeld (2004) or Huso estimator (Huso 2010) be used. When the removal time is greater than the search interval, the Shoenfeld estimator may underestimate and the Huso estimator may overestimate fatalities depending on the assumptions related to searcher efficiency over time. The Huso estimator may have less bias if it is modified so that searcher detection rate is for multiple searches as discussed above. Given that there is no perfect estimator, we recommend that fatalities be calculated using more than one estimator and if the fatality estimates are very different, then investigate the reasons for the difference.

## DECISION PROCESS

Fatality rates should be assessed relative to any regulatory requirement and to pre-construction predictions for the site. If fatality rates are approximately as predicted and are acceptable under the applicable regulatory requirement, then the objectives for fatality studies are typically met and no further study is needed to address fatality questions. When fatalities are greater than anticipated and exceed regulatory levels, the developer may choose from several options, such as conducting additional studies to determine if the initial fatality estimates are representative of what may occur at the facility, or implementation of additional mitigation measures, including potential risk reduction measures over and above what has already been undertaken prior to the project. In the latter case, more detailed studies usually will be necessary to evaluate the effectiveness of these additional measures.

# CHAPTER 5: IMPACT AND RISK ASSESSMENT, RISK REDUCTION, AND MITIGATION EVALUATION

## INTRODUCTION

Impact and risk assessment, risk reduction, and other mitigation evaluation studies typically are more complex, time consuming and expensive than routine fatality studies. They also are not necessary at many wind energy facilities. Because these post-construction studies will be highly variable and unique to the objectives and circumstances for the individual situation, it is impossible to provide specific information on all potential approaches to study. Consequently, the following material provides a general guide and case studies. Notwithstanding, all post-construction studies should follow the fundamental principles contained in Appendix C.

This chapter begins with a brief review of basic experimental designs, including the more classic manipulative and observational studies, and then evaluates designs that can be applied to the non-classic or "suboptimal" situations. Case studies are provided to illustrate how these designs have been used in the study of wind energy impacts on birds and bats. We also explore the manner in which individual animals and populations of animals respond to conditions of potential stress, including that caused by noise, visual disturbance, and other impacts, and provide suggestions for studying these impacts. Demographic and genetic responses at the population level are discussed, as are survivorship and projections on how populations might change in the future when confronted with changes to the environment. We provide an extensive discussion of ways to identify and monitor cumulative environmental impacts, and offer suggestions on risk reduction. We discuss the utility of models, including their uses, applications, and evaluation.

## PROBLEM FORMULATION

Whereas impact and risk assessment, risk reduction, and other mitigation evaluation studies are finalized, and in some cases entirely performed, after a project is constructed, the need for these studies is often identified during pre-construction problem formulation. This is true particularly when there is uncertainty over the extent to which a project will affect wildlife or uncertainty over how to minimize or mitigate unavoidable impacts. Problem formulation at this point addresses four major areas of interest related to wind energy impacts on wildlife:

- Impacts to habitat of species of interest, both direct and indirect
- Evaluation of methods for reducing risk
- Evaluation of the effectiveness of mitigation measures
- Evaluation of population and cumulative impacts

Given these areas of interest, habitat studies typically will occur only in situations where habitat impacts are of concern (e.g., habitat for prairie grouse, habitat for an endangered species) and there is uncertainty over how these impacts would be avoided, minimized, or compensated. Evaluation of risk reduction measures and the effectiveness of other mitigation measures may be required when fatality or other post-construction studies identify unexpected habitat or fatality impacts. Population impact studies will be necessary only on the rare occasion that fatality and/or habitat impacts suggest the potential for a reduction in the viability of an affected population. The final step in the problem formulation is the identification of the necessary site-specific methods and protocols needed to address questions related to habitat impacts and risk reduction and mitigation measures, which, beyond those related to fatality estimation, are the most important questions to be addressed.

## DESIGN CONSIDERATIONS FOR POST-CONSTRUCTION STUDIES

An optimal approach to post-construction studies is, in essence, the classic manipulative study. If the goal of the study is to identify the type, timing, and location of an impact that will occur, and pre-treatment data can be gathered, one is in an *optimal* situation to design the study. In the context of impact assessment, one might be establishing control areas and gathering pre-treatment data in anticipation of a likely catastrophic impact such as a fire or flood. Thus, the "when" aspect of the optimal design need not be known specifically, other than within a future for which one can plan (Green 1979).

However, in the case of wind energy development, although we can seldom anticipate precisely where an impact will occur, studies have improved our ability to narrow the range of landscape conditions where fatalities tend to concentrate or where habitat impacts are significant. Because animals are not distributed uniformly, even within a single vegetation type, we should sample intensively over an area in anticipation of a wind facility (the impact) that might never occur; few budgets can allow such luxury. (The topic of distribution of plots described below under suboptimal designs applies in this situation.) As noted by Green (1979), an optimal design is thus an area-by-time factorial design in which evidence for an impact is a significant areas-by-times interaction. Given that the prerequisites for an optimal design are met, the choice of a specific sampling design and statistical analyses should be based on one's ability to: (1) test the null hypothesis that any change in the impacted area does not differ statistically or biologically from the control; and (2) relate to the impact any demonstrated change unique to the impacted area and to separate effects caused by naturally occurring variation unrelated to the impact (Green 1979:71). Structuring pre-construction studies within a hypotheses-testing framework will help identify appropriate metrics, focus effort, and permit comparisons with post-construction conditions or other WRAs.

Often it is not possible to meet the criteria for development of an optimal design. Impacts often occur unexpectedly; for example, bird or bat fatalities may be unexpectedly high at an operating wind facility. In such cases, a series of *suboptimal study designs* are described. If the establishment of control areas is not possible, then the significance of the impact must be inferred from temporal changes alone (discussed below).

Unfortunately, impacts from wind energy development are typical of most other impacts that tend to occur without any pre-planning by the permitting authority or land manager. This common situation means that impacts must be inferred from areas that differ in the degree of impact; study design for these situations is discussed below.

In the sections below, we present case studies of the influence of wind developments on birds and bats that fall within the optimal to suboptimal study design framework.

### Habitat Effects

A variety of habitat-related effects of wind-facility construction can be envisaged. Some are associated with construction in general, whether from the wind generator or other related infrastructure. Other effects may result from the disturbance associated with the mere presence and operation of any type of anthropogenic features. Still others are specific to wind generators.

Some effects are transient, others are long-term, lasting either for the duration of operation of the wind facility or longer.

*Construction Activities*

Construction of structures such as wind facilities involves the alteration of habitat. The physical facilities – wind generators, converter stations, substations, roads to and between facilities, transmission towers, watercourse crossings etc. – occupy land that previously supported habitat for certain species. These disruptions will last for at least the life of the wind facility. Notwithstanding, the actual footprint of wind energy facilities occupies a relatively small portion of the WRA, on average 5-10% according to the BLM Programmatic Environmental Impact Statement (EIS) on wind energy development on public lands (BLM 2005).

Construction of roads and structures in many areas, such as native prairie, greatly increases the opportunity for invasion of undesirable species of plants. The access to formerly remote areas afforded by new roads may increase mortality of certain species, by legal hunting, illegal poaching, or collisions with vehicles. While the management treatment for these effects does not require study, the effects of these impacts may be uncertain and could be evaluated in a longitudinal study (Appendix C), in which changes over time in the abundance of affected species are compared between wind facilities and similar sites where construction did not occur. Another approach would be a gradient study (Appendix C), in which the abundance of the affected species is compared along a gradient from the disturbance site in areas with initially similar habitat.

Other construction activities, such as heavy traffic and equipment storage areas, are transient. Operation and maintenance activities, however, will continue. These involve periodic but infrequent visits to wind generators for inspection and repairs. Adequate structures should be placed during construction and maintained as needed to minimize soil erosion, sedimentation of water sources, and other potentially negative impacts to the environment.

Wind Generators

Wind generators may have influences different from other structures due to their height, motion of the blades, and emitted noise. Responses to these features very likely are species-specific, so generalizations should be made with caution.

The potential avoidance of tall structures, especially by certain grassland bird species, is a major concern of scientists. Another concern is fragmentation of habitat for some species. The concern is that a string of wind turbines may essentially fragment a large block of habitat. Certain bird species, for example, are area sensitive and generally do not use habitat patches below some minimum size. Suppose, for example, some grassland species require patches of at least 1,000 ha in size and refuse to pass through a string of wind turbines. A 2,000-ha habitat patch, if bisected by a string of wind generators, could be divided into two 900-ha patches (allowing 200 ha for the wind generators themselves); neither remaining patch would be of adequate size to support the species. Fragmentation effects on breeding birds could be estimated with some of the designs proposed for avoidance.

In addition to the potential reduction in breeding success due to reduced suitability of fragmented habitat, animals in the remaining patches could possibly suffer from reduced gene flow and difficulties in dispersal. In situations where fragmentation is confirmed, studies to detect these consequences necessarily would be species-specific and detailed.

It has been hypothesized that frequent movement of blades may be more intimidating to some animals than would be the case for the same structure if it were stationary. For example, Leddy et al. (1999) reported higher densities of birds when generators were idle than when they were functioning.

*Visual Disturbance and Displacement*
Drewitt and Langston (2006) reviewed the impacts of on- and off-shore wind developments on birds. They stated that the displacement of birds from areas within and surrounding wind facilities due to visual intrusion and disturbance can amount effectively to habitat loss. Displacement can occur during both the construction and operational phases of wind facilities, and can be caused by the presence of the turbines themselves through visual, noise and vibration impacts, or as a result of vehicle and personnel movements related to site maintenance. The scale and degree of disturbance will vary according to site- and species-specific factors and must be assessed on a site-by-site basis. They noted, however, that few studies of displacement due to disturbance are conclusive, often because of the magnitude of the effect, the precision of the study, and the lack of BACI assessments. For onshore studies, disturbance distances were defined as the distance from wind facilities to where birds are absent or less abundant than expected. Distances from 0-800 m have been recorded for wintering waterfowl, although much shorter distances (100-200 m) were found for other species. Onshore studies illustrating displacement were previously discussed in Sections 1.0 and 2.0 above. As noted by Drewitt and Langston (2006), the consequences of displacement for breeding productivity and survival are crucial to whether displacement has a significant impact on population size.

Drewitt and Langston (2006) also considered the potential effects of birds altering their migration flyways or local flight paths to avoid a wind facility, which would also be a form of displacement. This effect is of concern because of the possibility of increased energy expenditure when birds have to fly further and the potential disruption of linkages between distant feeding, roosting, molting and breeding areas otherwise unaffected by the wind facility. The effect of this type of displacement would depend on species, type of bird movement, flight height, distance to turbines, layout and operational status of turbines, time of day, and wind force and direction. Flight alterations could be highly variable, ranging from a slight change in flight direction, height or speed, to significant diversions that may reduce the numbers of birds using areas beyond the wind facility. The literature review by Drewitt and Langston (2006) indicated that none of the displacement identified so far have significant impacts on populations. However, there are circumstances where the displacement might lead indirectly to population level impacts; for example, if a wind facility effectively blocked a regularly used flight line between bird nesting and foraging areas, or if wind facilities interacted cumulatively to create an extensive barrier which lead to bird flight diversions of many tens of kilometers, then theoretically increased energy costs could occur for those birds. While these impacts are likely negligible at the current level of development, the effect of increased energy costs associated with wind energy facility avoidance will increasingly be a concern.

The following case studies illustrate the study of behavioral response to wind energy development and the resulting potential loss of habitat due to displacement.

**Habitat Case Studies: Optimal Study Designs**

*Radio Telemetry and the Study of Population Impacts*
Kansas State University, as part of the NWCC Grassland Shrub-steppe Species Collaborative (GS3C), is undertaking a multi-year research project to assess the effects of wind energy

facilities on populations of greater prairie-chickens (GPCH) in Kansas. Initially the research was based on a Before/After Control/Impact (BACI) experimental design involving three replicated study sites in the Flint Hills and Smoky Hills of eastern Kansas. Each study site consisted of an impact area where a wind energy facility was proposed to be developed and a nearby reference area with similar rangeland characteristics where no development was planned. The research project is a coordinated field/laboratory effort, i.e., collecting telemetry and observational data from adult and juvenile GPCH in the field, and determining population genetic attributes of GPCH in the laboratory from blood samples of birds in the impact and reference areas. Detailed data on GPCH movements, demography, and population genetics were gathered from all three sites from 2007 to 2010. By late 2008, only one of the proposed wind energy facilities was developed (the Meridian Way Wind Farm in the Smoky Hills of Cloud County), and on-going research efforts are focused on that site. The revised BACI study design now will produce two years of pre-construction data (2007 and 2008), and three years of post-construction data (2009, 2010, and 2011) from a single wind energy facility site (impact area) and its reference area. Several hypotheses were formulated for testing to determine if wind energy facilities impacted GPCH populations, including but not limited to addressing issues relating to : lek attendance, avoidance of turbines and associated features, nest success and chick survival, habitat usage, adult mortality and survival, breeding behavior, and natal dispersal. A myriad of additional biologically significant avenues are being pursued as a result of the rich data base that has been developed for GPCH during this research effort. GPCH reproductive data will be collected through the summer of 2011 whereas collection of data from transmitter-equipped GPCH will extend through the lekking season of 2012 to allow estimates of survival of GPCH over the winter of 2011-2012. At the conclusion of the study, the two years of pre-construction data and three years of post-construction data will be analyzed and submitted to peer-reviewed journals for publication.

A similar study is underway in Wyoming to evaluate effects of wind energy development on greater sage-grouse (Johnson et al. 2010, Beck et al. 2011), and other studies are planned so that the estimation of impacts will be based on multiple study sites. Survival will be estimated from telemetry data by viewing relocation attempts as capture occasions, and applying the Cormack-Jolly-Seber capture-recapture model (Amstrup et al. 2005; Appendix C). Explanatory covariates (such as winter severity, gender, season) will be incorporated into the model, and the best-fitting model identified by AIC (Burnham and Anderson 2002). Breeding season, summer, and winter survival will be estimated. The investigators will estimate the 95% fixed-kernel (Wand and Jones 1995) home range for all radio-marked individuals and the marked population as a whole. Home-range estimates (both individual and population) will be plotted on maps and areas of high and low density will be identified for the breeding, summer and winter seasons. Resource Selection Functions (RSFs) (Appendix C) will be used to develop statistically rigorous habitat models to predict the distribution of sage-grouse across the landscape (Manly et al. 1993). Similar RSFs developed with data collected following construction of the wind energy facility will allow the investigators to measure changes in habitat use (i.e., displacement) in response to presence of the facility.

Vital rates (nest success, survival, and chick productivity) will be incorporated into matrix-based population growth models. These models will be used to estimate which vital rates are relatively important to population sustainability and to establish which vital rates are responsible for any differences in population growth measured after the facility is constructed and operated. This information is important for guiding management decisions if an effect is detected.

These two grouse studies illustrate how telemetry can be used to evaluate the displacement effect of wind energy facilities, the subsequent habitat impacts, and the potential demographic effects to grouse populations. While the strongest inference comes from true experiments (Appendix C), replication of individual observational studies is valuable in establishing cause and effect relationships that can be generalized to other situations. Johnson (2002) pointed out that similar conclusions obtained from studies of the same phenomenon conducted under widely differing conditions gives greater confidence in the in the generality of those findings than any single study.

*The Northern Prairie Design for Habitat Impacts*

At several sites in North and South Dakota, the USGS Northern Prairie Wildlife Research Center is investigating whether grassland birds exhibit an avoidance to wind turbines during the breeding season (Shaffer and Johnson 2008). Intensive transect surveys are conducted within gridded study plots that contain turbines, as well as at undeveloped reference areas. Depending on the study areas with turbines, distances of 700 m to 1000 m from turbines were sampled. By surveying an extensive area, rather than a single transect, the surveyed area around each turbine is maximized. Surveys are conducted: (1) at sites where turbines will be constructed (treatment sites) and the same sites after construction, which provide before-and-after-treatment comparisons; and (2) at similar (control) sites where turbines were not constructed, which provide comparisons between treated and untreated sites, i.e., a BACI design. Control areas are chosen to match as closely as possible the topography, habitat, and land use of treatment sites. All species seen or heard during the surveys are mapped (Figure 5.1).

Populations of many species of birds fluctuate, often dramatically, from one year to another. For that reason, if an estimate of density is desired it is advisable to survey birds for several years, both before and after construction. However, because of the nature of the wind industry, it rarely has been feasible to collect data on breeding birds for more than one season before construction commences. Nevertheless, data can be gathered for several years following construction. Multiple years of data provide an estimate of the annual variation in post-construction bird abundance . Multiple years of post-construction data may also be necessary if the effect of the wind development on a population is not be manifested for two or more years. Conversely, some birds may show an avoidance of wind turbines immediately after construction, but gradually become acclimated to them. In this circumstance, it may be reasonable to conduct surveys on a less-than-annual basis, for example, one, three, and five years after construction.

In addition to estimating densities of each bird species at each site, the Northern Prairie design determines the distance between each recorded bird and the nearest wind turbines. That information permits the investigators to assess the distance, if any, at which birds avoid the turbines.

Investigators conduct two or more censuses of birds on each site during the breeding season. A census grid is established surrounding each wind turbine. Grids extend until there is an obvious change in either composition of plant species (e.g., from native to tame grasses) or land treatment (e.g., grazed, cropland, hay land), or until the grid line reaches 800 m (0.5 mi) from the wind turbine. Grid lines are 200 m apart and marked off in 50-m intervals with fiberglass electric fence poles (Figure 5.1). Observers slowly walk a path that crosses the grid lines at a perpendicular orientation every 100 m and map locations of birds within 50 m on either side. Similar grids are established at control sites, but of course there are no wind turbines, and bird mapping is done the same as at treatment sites. The type of bird location data collected through conducting these surveys is shown in Figure 5.1.

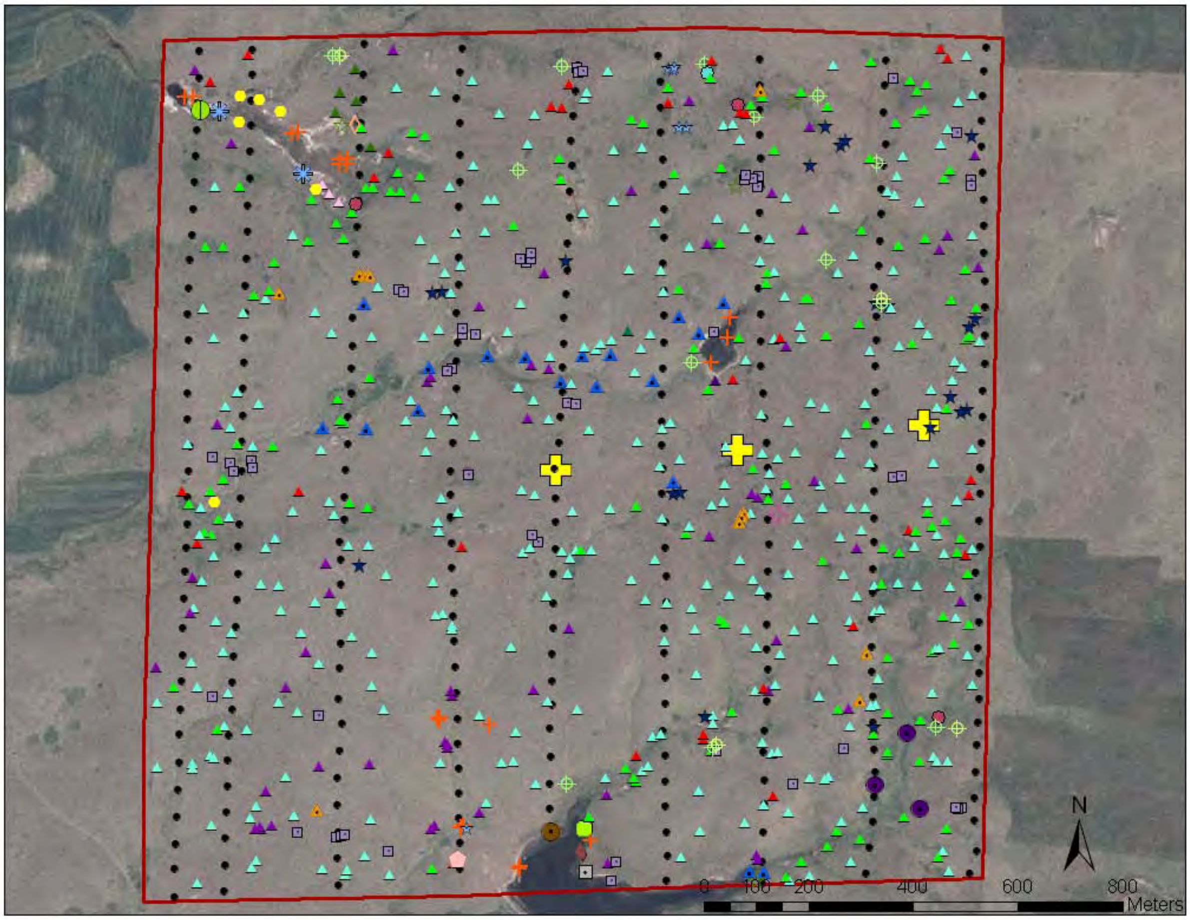


**Figure 5.1. Results of one bird survey at a wind-energy facility (Shaffer and Johnson, Northern Prairie Wildlife Research Center, Jamestown, North Dakota, unpublished data). Each symbol and color represents a different bird species. Yellow crosses represent locations of wind turbines. Black circles represent locations of fiberglass electric fence poles that act as grid markers.**

Because bird activity and detectability vary with a number of factors, censuses were conducted only between 15 May and 15 July, and from 0.5 h after sunrise to 1100 h. Censuses were further restricted to days of good visibility and good sound detectability.

Each bird seen or heard within a census grid was counted and recorded by its American Ornithologists' Union (AOU) code. Birds flying overhead were noted but counted as being within the transect only if they were flying low and presumably feeding or hunting.

*Vegetation Surveys*. Because different bird species have certain habitat preferences, it was necessary to classify and map major vegetation types in the census plots. Four major habitat types sufficed for the Northern Prairie study sites: (1) xeric herbaceous vegetation, (2) mesic herbaceous vegetation, (3) woody (shrubby) vegetation, and (4) wetland. Mapping was conducted by on-site inspection.

For each habitat type within a study plot, vegetation structure was measured. Potential vegetation sampling points were the set of all points located at 50-m intervals along grid lines. For a study plot of, say, 100 ha, investigators measure vegetation structure at 25 of these points. The distribution of these points among habitat types was proportional to the square root of the area of each habitat type in the study plot. At each chosen sampling point, vegetation height, litter depth, and visual obstruction were recorded.

Percent composition of six basic life forms – bare ground (bare ground, cow pie, rock), grass, forb, shrub, standing residual, and lying litter – is estimated using a step-point sampler (Owensby 1973). Maximum vegetation height and litter depth are measured with a meter stick, and a Robel pole is used to measure visual obstruction (Robel et al. 1970).

*Analysis*. Analysis primarily involved the comparison of numbers of birds observed (by species) at various distances from a turbine to the number expected if birds were distributed randomly with respect to turbines. For each observation of a species, the distance from the bird's location to the nearest wind turbine was calculated. For comparison, 10,000 points were generated randomly within each study plot. If a particular portion of the study plot was unsuitable for a species (e.g., prairie dog colonies for grasshopper sparrows), that portion was excluded when random points were chosen. The distance from each random point to the nearest wind turbine was computed. The distribution of those distances provided a basis for comparison with the distances of birds from wind turbines. If birds showed no avoidance of the turbines and were randomly located in the study area, their distribution should not differ substantially from the random distribution. Avoidance of (or attraction to) wind turbines would be reflected in consistent departures from the random distribution.

Distance values were grouped into 50-m categories (i.e., 0-50 m, 50-100 m, etc.) and the number of bird observations in each distance category was calculated. Distances of random points were grouped similarly, and the numbers in each category were scaled so they totaled the same as the number of bird observations. These values represent the number of birds expected in a distance category under the assumption that birds are distributed randomly with respect to the wind turbines. Then, for each distance category, the difference between the number of bird observations and the scaled number of random points was taken, and these differences were graphed against the distance category. Graphs were made both for the pre-construction data and the post-construction data, as well as for comparable data collected at control sites. The important information pertains to differences near wind turbines, that is, at smaller distance categories.

Figure 5.2 shows the distribution of differences for a single pre-construction survey of an unspecified species. Note that there is no consistent pattern of departures at nearer distances. This would be expected, of course, because there were no wind turbines to avoid at that time. After construction, however, a pattern of avoidance was evident (Figure 5.3, representing three post-construction years), with fewer observations than expected in the first four distance categories, that is, out to 200 m.

The authors compared observed versus expected distances to identify displacement effects. The study focused on four species at two study sites, one in South Dakota and one in North Dakota. Based on this analysis, killdeer (*Charadrius vociferous*), western meadowlark (*Sturna neglecta*), and chestnut-collared longspur (*Calcarius ornatus*) did not show any avoidance of wind turbines. However, grasshopper sparrow showed avoidance out to 200 m.

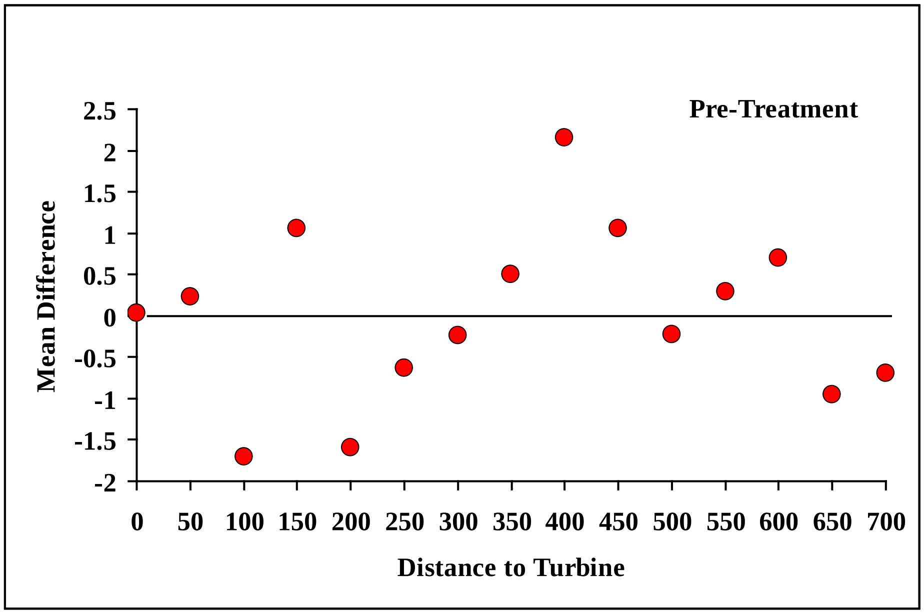


**Figure 5.2. Differences between number of detected birds of a particular species and number expected under the assumption that birds were located randomly with respect to wind turbines, in relation to distance from nearest turbine; data are from a study site before wind turbines were constructed.**

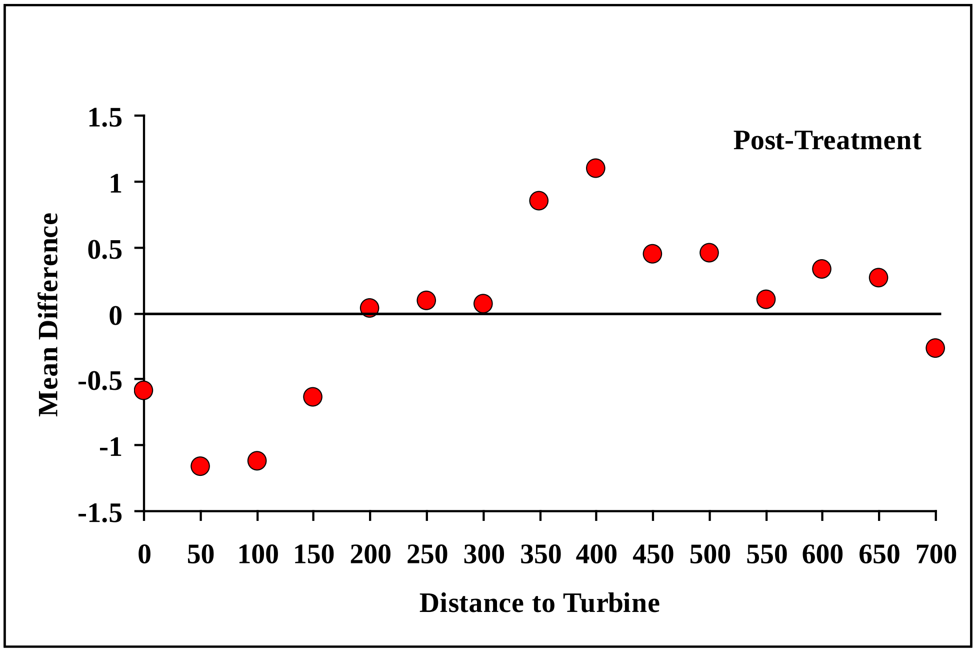


**Figure 5.3. Differences between number of detected birds of a particular species and number expected under the assumption that birds were located randomly with respect to wind turbines, in relation to distance from nearest turbine; data are from a study site for the first three years after wind turbines were constructed.**

Although it is possible to perform some statistics on a single data set, it is far more appropriate to look for consistent patterns at different study sites and in different years before drawing conclusions (Johnson 2002). For this reason, the Northern Prairie continues their research at these two sites while adding other study sites to their study.

Similar to the telemetry case study, the Northern Prairie study attempts to quantify displacement of birds from wind energy facilities. Unlike the previous example, the empirical data collected in this study are the number of birds observed in the study area. Furthermore, observations were grouped by distance intervals from the nearest wind turbine. No effort was made to relate displacement to demographic characteristics of the local population of birds.

*Grassland Birds in the Pacific Northwest: Impact Gradient*
Erickson et al. (2004) conducted surveys of breeding grassland birds along 300-m transects perpendicular to strings of wind turbines. In this case the study conformed to a special case of BACI where areas at the distal end of each transect were considered controls (i.e., beyond the influence of the turbines). Surveys were conducted prior to construction and after commercial operation. The basic study design follows the *Impact Gradient Design* (Appendix C). The addition of pre-treatment results, to contrast with post-treatment data, represents a valuable enhancement over treatment and control designs such as used by Leddy et al. (1999), which is described below as an example of a suboptimal design. Erickson et al. (2004) found that grassland passerines as a group, as well as grasshopper sparrows and western meadowlarks, showed reduced use in the first 50-m segment nearest the turbine string. About half of the area within that segment, however, had disturbed vegetation. Horned larks and savannah sparrows (*Passerculus sandwichensis*) appeared unaffected.

This case study is similar to the above case studies in that it is observational. Yet, as there is no attempt to census birds in the area, observations per survey are used as an index of abundance. Additionally, the impact-gradient study design resulted in slightly less effort than the BACI design with control areas. It should be noted that the impact gradient design is best used when the study area is relatively small and homogeneous.

*Buffalo Ridge Minnesota: BACI Design*
The Buffalo Ridge WRA in southwest Minnesota consisted of three major phases of development during a 4-year study from 1996 to 1999. Data also were collected on a reference area (RA) along Buffalo Ridge northwest of the WRA in Brookings County, South Dakota so that a BACI sampling design (Green 1979) could be used to assess displacement impacts to birds (Johnson et al. 2000a). To assess small-scale displacement, avian point counts were conducted at staked turbine locations prior to construction and at the same turbines following construction. To assess large-scale displacement impacts, point-count surveys also were conducted at 71 points located from 100-300 m away from roads to ensure they were placed in areas representative of turbine locations. These points ranged from 105-5,364 m from the nearest turbine. Surveys were conducted at each point once every two weeks during the summer (15 May-15 August). Surveys were conducted between 1/2 hour before sunrise and four hours after sunrise. At survey plots, all birds including flying birds detected by sight or sound were recorded within 100 m of the observer for a 5-minute period. For each observation the species, number, estimated distance from the observer, activity, and cover type were recorded. Adjustments for visibility bias (Buckland et al. 1993) were estimated by species when data were sufficient using the program DISTANCE (Laake et al. 1993).

Effect estimates were calculated for taxonomic groups and for 17 species of birds that breed primarily in grasslands. To assess small-scale effects of turbines, avian use estimates (#/survey) for reference (non-turbine) plots following turbine construction were divided by use estimates for the same reference plots prior to turbine construction. This reference post- to pre-construction ratio was then divided into the corresponding post- to pre-construction ratio for the turbine plots. For example, if mean use by species A on all reference plots was 2.0/survey prior to and 3.0/survey following turbine construction, the reference ratio for the post- to pre-construction periods was 3.0/2.0 = 1.5. If mean use by species A at turbine plots was 2.4/survey prior to and 2.0/survey after construction, then the post- to pre-construction ratio would be 2.0/2.4 = 0.83. The effect estimate was then calculated as the ratio of the turbine ratio to the reference ratio (0.83/1.50 = 0.55). A 90% bootstrap confidence interval (Manly 1991) was obtained for the effect estimate, and significant changes relative to the reference sites were indicated when the confidence interval did not capture the value 1. An effect estimate <1 indicated a negative effect (decrease in use) due to the turbines, whereas an effect estimate >1 indicated a positive effect (increase in use).

Post-construction avian use of turbine plots during the breeding season was lower than expected for raptors and passerines in 1998, the first year after construction and for raptors, upland game birds, and passerines in 1999, two years after construction. Groups of passerines that showed decreased use included sparrows, swallows, wrens and warblers. Horned larks showed higher than expected use, while no change in use was detected for the other 12 avian groups analyzed. There was also a negative wind power development effect on avian richness (defined as number of species/plot survey). For grassland breeding birds during the first year following construction, the BACI analysis indicated that use of turbine plots was lower than expected for common yellowthroat (*Geothlypis trichas*) and northern harrier. However, use was greater than expected for horned lark and vesper sparrow *(Pooecetes gramineus*). Two years following construction, use of turbine plots was lower than expected for bobolink (*Dolichonyx oryzivorus*), Wilson's snipe (*Gallinago delicata*), common yellowthroat, grasshopper sparrow, ring-necked pheasant (*Phasianus colchicus*), savannah sparrow, and sedge wren (*Cistothorus platensis*), as well as for all grassland breeders combined. One species, dickcissel (*Spiza americana*), showed significantly higher than expected use.

The only avian group with lower than expected use of non-turbine point count plots following turbine construction was waterfowl the first year following construction; use by all avian groups was similar to expected two years following construction. The northern harrier, the first year after construction, was the only grassland species with lower than expected abundance at non-turbine plots during the breeding season. Two years following construction, use by northern harriers was similar to expected. No other significant effects were detected for any of the other 16 species examined or for all grassland breeders combined.

The Buffalo Ridge study answered the question of displacement by estimating use at survey points, rather than along transects. Nevertheless, the data are similar to those collected using the impact gradient design described above (Erickson et al. 2004) and allowed a quantification of the displacement effect of wind turbines at this site.

**Suboptimal Designs: Case Studies of Habitat Impacts**

In an early study of the effects of wind turbines on grassland birds, Leddy et al. (1999) established transects running parallel to a string of turbines at distances of 0 m (directly underneath turbine string), 40 m on each side of string, 80 m on each side of string, and 160 m on one side of string. They also established a transect in each of three control fields with similar vegetation. All fields were enrolled in the United States Department of Agriculture (USDA) Conservation Reserve Program with vegetation consisting of grasses and alfalfa (*Medicago sativa*) that had been planted 7-8 years earlier. Observers surveyed birds along these transects weekly from 15 May to 1 July, from sunrise to 10:00 AM, and under suitable weather conditions. Counts were made of perched or singing males within 20 m of each transect, and counts from all surveys were averaged. Note that, because wind turbines in strings were 91-183 m apart, the distance from the string may not reflect distance from the nearest wind turbine. For example, points along the transect running underneath the turbines string could be as much as 91 m from the nearest turbine, equivalent to points along the 80-m-away transect that are perpendicular to the string.

Leddy et al. (1999) reported 15 percent higher densities of birds (all species combined) when turbines were idle than when they were functioning, and higher densities of birds in the control fields than in the fields with wind turbines. Species composition varied somewhat between CRP fields with and without turbines, suggesting either: (1) the habitat varied between the two types of fields; or (2) species responded differently to the turbines. Subsequent research elsewhere has borne out the latter possibility (Shaffer and Johnson, unpublished information). Density of all species combined increased monotonically with distance from the string of wind turbines (Figure 5.4).

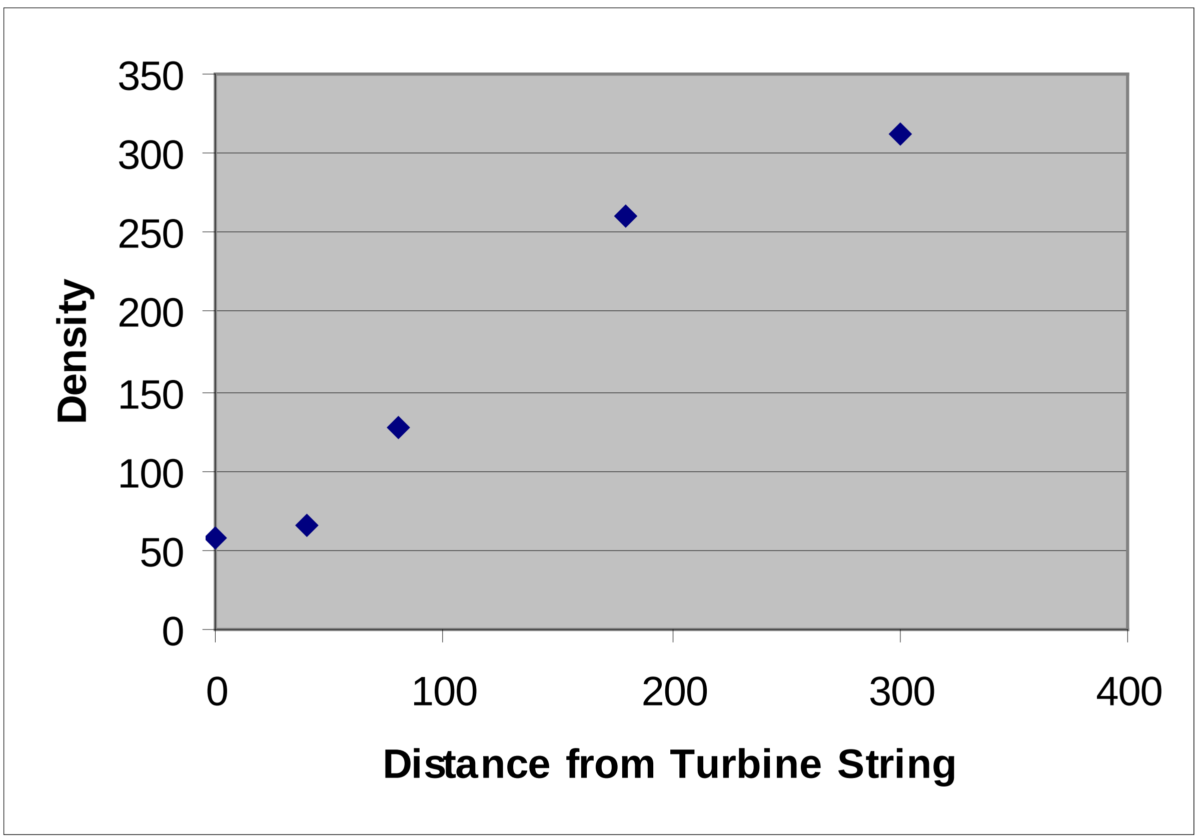


**Figure 5.4. Density (per 100 ha) of singing or perched male birds, all species combined, in relation to distance from a wind generator, in a site in southwestern Minnesota (from Leddy et al. 1999). Note that the point at 300 m actually reflects results from three control sites in which no wind generators were located.**

The Leddy et al. (1999) study evaluated the same basic hypothesis evaluated by the Stateline (Erickson et al. 2004) and Buffalo Ridge (Johnson et al. 2000a) studies, albeit with a different study design. Like the previous Buffalo Ridge study this study design included control areas. However, the Leddy et al. (1999) study lacked replication of transects within the control fields, making true estimation of the variance in the estimate impossible. The primary difference between the Stateline study and this study is the orientation of transects in relation to the turbine strings. Either approach to sampling can be effective; although the Leddy et al. (1999) approach complicated the analysis of distance effects and lost the advantage of the impact-gradient design.

## INDIVIDUAL AND POPULATION ASSESSMENT

In this section we review and discuss the factors that can potentially impact animals at the individual and population levels. Changes in an animal's environment may affect it physiologically and cause changes in behavior. At the population level, if these changes are significant we can expect potential changes in demography, genetics, and survival, and ultimately changes in population trends through time. We also discuss in detail potential cumulative effects caused by a combination of factors influencing animals. Lastly, this section presents a guide to study designs for risk reduction.

### Analysis of Stress and Physiological Changes

Because of the difficulty in relating post-impact differences to treatment effects in the absence of data from reference areas, injury indicators can be particularly useful in detecting impacts using Before-After Design. The correlation of exposure to toxic substances and a physiological response in wildlife has been documented well enough for some substances to allow the use of the physiological response as a *biomarker* for evidence of impact. Examples of biomarkers used in impact studies include the use of blood plasma dehydratase in the study of lead exposure, acetylcholinesterase levels in blood plasma in the study of organophosphates, and the effect of many organic compounds on the microsomal mixed-function oxidase system in the liver (Peterle 1991).

Models of genetic variation have a central role in the conservation of populations. Local populations or subpopulations may contain the genetic diversity that is necessary to ensure survival of the species within a region, or even throughout its range. However, we are particularly interested in how extremely small population size can result in inbreeding depression and a reduction in genetic variation, both of which can lead to extinction (Boyce 1992). Boyce (1992) concluded that modeling genetics is not likely to be as important as modeling demographic and ecological processes in evaluating population persistence. He based this conclusion, in part, on the fact that we do not yet understand genetics sufficiently to use it as a basis for management. Thus, practical considerations were the overriding factor in his conclusion. However, genetics will be of priority in small, isolated populations, and could potentially have applicability in some studies of wind energy/wildlife interactions. For example, low genetic diversity has been correlated with inbreeding depression (reduced egg viability and smaller clutch sizes) in both greater prairie-chickens (*Tympanuchus cupido*) and Gunnison sage-grouse (*Centrocercus minimus*; Westemeier et al. 1998, Stiver et al. 2008). Conversely, high levels of genetic diversity in greater prairie-chickens have been found to enhance fitness by increasing breeding opportunities (Gregory 2011) and disease resistance (Eimes et al. 2011). While more research is needed on this topic, assessing baseline genetic diversity in small, isolated grouse populations in and around proposed development might be useful in assessing the vulnerability of the population to disturbance, isolation, and population decline.

In addition to assessing genetic diversity, genetic data potentially might be useful in assessing the effects of development to disruption of mating system, and life history strategy. For example, McNew (2010) found that greater prairie chickens responded to changes in the environment by increasing or decreasing reproductive effort which included intra-specific brood parasitism and an increase in polyandry (Gregory 2011). While more research is needed on this topic, assessing maternity and paternity of broods might provide an approach to assess behavioral changes to the lek breeding system as a result of environmental disturbance.

*Noise*

As reviewed by Katti and Warren (2004), few researchers have addressed the implications of anthropogenic noise for acoustic communication systems in animals. For example, Slabbekoorn and Peet (2003) showed that birds can respond to elevated background noise by altering their songs. They found that urban great tits (*Parus major*) at noisy locations in the Dutch city of Leiden sang with a higher minimum frequency than do those in quieter locations. They concluded that this apparent behavioral adaptation might help them to overcome the effects of the lower frequency background noise, characteristic of cities, which could mask the songs and make them more difficult to hear. The mechanisms underlying the reported frequency shifts in bird song are not yet understood. Recent studies have, however, found evidence for genetic differences between city and forest populations of songbirds, and it is possible that genetic differences might play a role in the differences between songs of urban and forest birds (Partecke et al. 2004, 2006).

More specifically, Partecke et al. (2006) hand-raised urban and forest-living individuals of the great tit under identical conditions and tested their corticosterone stress response at an age of 5, 8, and 11 months. The results suggest that the difference is genetically determined, although early developmental effects cannot be excluded. Either way, the results support the idea that urbanization creates a shift in coping styles by changing the stress physiology of animals. The reduced stress response could be ubiquitous and, presumably, necessary for all animals that thrive in ecosystems exposed to frequent anthropogenic disturbances, such as those in urban areas.

Dooling (2002) addressed the potential that noise generated by wind turbines might caused birds to avoid turbines and concluded that it is possible, however, that as birds approach a wind turbine, especially under high wind conditions, they lose the ability to see the blade (because of motion smear) before they are close enough to hear the blade. This blade smearing was confirmed in laboratory experiments by Hodos (2003). Noise may very well play some role in displacement effects, although the effect of noise is hopelessly confounded with other factors such as moving blades, traffic, subtle changes in vegetation and topography, and human activity. Separating the effect of these individual factors potentially causing displacement will require controlled experiments. For example, the hypothesis that louder (to birds) blade noises result in fewer fatalities could be tested.

## Demography

The five basic components of demography, along with population size, are mortality, reproduction, emigration, and immigration.

*Mortality*

Although the numbers of birds and bats killed in collisions with wind generators can be large at some facilities (e.g., eagles at APWRA in California [Orloff and Flannery 1992, Hunt 2002] and bats at Mountaineer in West Virginia [Kerns and Kerlinger 2004, Arnett 2005]), determining the population-level effects of those mortalities is generally impossible, primarily because little is known about the demography of the affected populations or the populations are so large as to make population impacts from the level of fatality unlikely. Nevertheless, concern over potential population effects is elevated for very small populations or populations restricted to a small area. Hunt (2002) completed a 4-year radio-telemetry study of golden eagles around the APWRA to determine the demographic effect of the relatively high number of annual fatalities within the WRA. Reproductive and mortality data were collected from radio-tagged birds and these data were used to calculate lambda, the population rate of increase. Hunt's estimation of lambda indicated that the local population is self-sustaining, although he postulated that fatalities resulting from wind power production were of concern because the population apparently depends on immigration of eagles from other subpopulations to fill vacant territories.

Additional radio-telemetry studies similar to Hunt (2002) could be used to estimate mortality rates for local populations. Such a study is underway in Kansas, involving greater prairie-chickens (see section on "Habitat Case Studies: Optimal Study Designs" in this chapter). A similar study is underway for mallards (*Anas platyrhynchos*) in North Dakota, where females will be fitted with transmitters, tracked during the breeding season, and any collisions with wind generators reported.

*Reproduction*

Telemetry studies, such as the ones mentioned above, could also be used to estimate reproduction rates and compare them between sites near wind generators and sites distant from generators. For example, while wind generators may not directly influence reproductive rates, it is theoretically possible that displaced nesting females may settle in less suitable habitat, making them more susceptible to predation. It is also theoretically possible that wind facilities may attract predators (e.g., raptors) by providing increased perching opportunities. Hunt (2002) hypothesized that increased ground squirrels and numerous perching opportunities in the APWRA attracted eagles and contributed to the relatively high eagle fatalities at those facilities.

*Emigration and Immigration*

Emigration or immigration rates could theoretically change in response to wind generators if birds or bats avoid them or are attracted to them, respectively. These topics, especially avoidance, are discussed in relation to fatality modeling and other baseline studies in Chapter 3.

**Isotopic and Genetic Analyses**

*Isotope Analyses*

The use of stable isotopic markers in bird feathers has revealed promising new directions for tracking migratory birds and other wildlife (Hobson and Wassenaar 2001). A clear advantage of this approach is that it does not require marking birds on their breeding grounds or in locations where feathers are grown (Hobson and Wassenaar 2001), or the recapture of banded species to make confident conclusions. With stable isotopic markers, the isotopic signature of a tissue reflects the isotopic signature of the local environment where the tissue was grown (Royle and Rubenstein 2004). Isotopic base maps of growing season precipitation have been created for North America (Lange et al. 2007). A comparison between the isotope signature of the sample species and isotopic region map can then be made to determine a likely location of origin of the specimen. Feathers with isotopic signatures are developed when juveniles grow their first set of feathers and when adults replace molted feathers (Hobson et al. 2007). The feathers will maintain the distinct signature provided by the food web in which they foraged, thereby making it possible to determine a bird's geographic fingerprint of natal origin (Hobson 1999).

Stable isotopic analysis is also applicable to mammals, such as bats. Bats have been inherently hard to track through banding; however, the use of stable isotopes to define the origins of migrating bats could simplify the process. Like bird feathers, mammalian hair is composed mainly of keratin, so feathers and hair may incorporate hydrogen in a similar manner during growth (Cryan et al. 2004). Bats typically molt into new pelage just once per year, so it is reasonable to assume that the stable hydrogen isotope ratio of bat hair will reflect isotopes of the locale where the hair was grown (Cryan et al. 2004). Studies have shown the capability to designate specific individuals as year-round residents at a sample site based on isotope signatures, while others produced signatures consistent with regions 2,000 km from the same sample site (Cryan et al. 2004).

The use of stable isotopes has several applications for studying wind energy impacts on birds and bats. For example, isotopic analysis could be used to determine the number of resident versus migrant bird or bat fatalities found at a wind energy facility. Determining the level of impacts or population consequences often requires knowledge of whether resident or migrant populations are involved. As another example, many states maintain a list of state threatened and endangered species. Even though the State of Illinois classifies northern harriers as an endangered species due to loss of grassland breeding habitat in the state, this is one of the most common raptors observed during winter avian use surveys of WRAs in Illinois (WEST, Inc., unpublished data). If northern harrier fatalities occur once these facilities are constructed, isotope analyses could be used to determine if the individual was from the local, endangered breeding population or a migrant from a breeding population in another state or Canada.

If mist-net surveys are conducted as part of a pre-construction study, feather (or hair) samples could be collected from captured individuals to determine if the project area was being used primarily by resident or migrant individuals. Also, if impacts to birds or bats are occurring, isotope analyses could be used to determine where the impacted populations breed, and mitigation efforts could be concentrated in those areas to increase breeding populations of the affected species.

*Bat Genetics*

Most of the bats found as wind turbine fatalities are comprised of three migratory tree bats, namely the hoary bat, eastern red bat, and silver-haired bat (Johnson 2005, Kunz et al. 2007b, Arnett et al. 2008). Because these species are primarily solitary tree dwellers that do not hibernate, it has not been possible to develop suitable methods to estimate their population sizes. As a result, impacts on these bat species caused by wind energy development cannot be placed in demographic perspective.

To help solve this problem, population genetic analyses of DNA sequence and microsatellite data are being conducted to provide effective population size estimates, to determine if populations are growing or declining, and to see if these species in North America are comprised of single large populations or several discrete subpopulations that use spatially segregated migration routes (A.L. Russell, Assistant Professor, Grand Valley State University, Allendale, Michigan, pers. comm.).

To date, initial analyses have been conducted only for eastern red bats using mitochondrial DNA. Based on these analyses, it appears that this species fits a model of a single, large (~ 3.3

million) population with a history of strong population growth (Vonhof and Russell [in press]). The data do not suggest there are multiple populations separated by distinct migratory corridors. Similar analyses are being planned for hoary and silver-haired bats once funding becomes available (A.L. Russell, pers. comm.)

Because mitochondrial DNA is inherited only through the mother, changes in mitochondrial DNA track trends in female population sizes, but do not provide information on males. Also, change in mitochondrial DNA provides information only on long-term trends in population sizes, whereas data from more quickly evolving loci are required to detect any recent effects of wind turbine mortality on these populations.

Analysis of autosomal DNA, from the 22 pairs of non-sex chromosomes found in the nucleus, will provide data for males similar to what mitochondrial DNA data provide for females. Variation at microsatellites is influenced by more recent changes in demographic parameters than variation in DNA sequence data. Current research is being proposed to analyze microsatellite data to determine if there are recent population declines resulting from wind turbine fatalities. In combination, these studies will provide estimates of current population sizes, changes in population sizes over time, and patterns of population subdivision and connectivity across the landscape that are not limited in terms of sex or time scale (A.L. Russell, pers. comm.). These estimates are critically important to assessing the long-term impact of wind turbines on migratory tree bat species in North America.

**Determining Cumulative Effects**

Cumulative effects are an important topic in the evaluation of environmental impacts. Neufeldt and Guralnik (1988) define cumulative as “increasing in effect, size, quantity, etc., by successive additions.” As is often the case, a relatively simple term takes on a very complicated meaning when applied to natural resources and their response to perturbations. To complicate matters, the term is defined differently by federal law such as the NEPA and its implementing regulations. Suter et al. (1993) classifies cumulative effects into the following categories:

- *Nibbling* **-** the cumulative effects of a number of actions that have similar small incremental effects. For example, the additions of individual turbines to a wind facility, or the addition of new wind facilities to the range of a wide-ranging breeding population of a species.
- *Time-Crowded Perturbations* **-** the cumulative effects that occur when actions are so close in time that the system has not recovered from the effects of one before the next one occurs. For example, if impacts from wind turbines are influenced by birds’ experience with the structures, one could anticipate some learned response to the turbines over time, possibly reducing risk. One could hypothesize that rapid development of a wind facility might have a greater impact on birds than phased development of the same facility.
- *Space-Crowded Perturbations* **-** the cumulative effects that occur where actions are so close in space that the areas within which they can induce effects overlap. For example, bird risk may be influenced by turbine and turbine string spacing.
- *Indirect Effects* **-** the cumulative effects that occur when the direct effects of actions are not space- or time-crowded, but the indirect effects are. For example, the change in land use resulting from a wind facility may not affect bird use or cause increased mortality, but may affect habitat quality, either positively or negatively.

Cumulative effects analysis involves the study of the interaction of wind facility structures, other land uses, and the ecology of wildlife. Effects of wind facilities on wildlife may be *additive*, increasing mortality and/or habitat loss beyond what might occur without the facility; or effects may be *compensatory*, simply replacing other sources of mortality. Effects of wind facilities may be *synergistic*; that is, a wind facility in combination with another land use may result in an increased rate of bird mortality or habitat loss greater than the sum of increased mortalities or habitat loss that might occur due to each individual development. Or, effects may be *antagonistic*, in which case association with some other variable would reduce impacts from the wind facility. Finally, impacts of a wind facility may increase to a limit or threshold of effect. As with testing hypotheses of first order direct effects, the key to a successful analysis is the protocol by which the data are collected.

There are two major aspects to cumulative effect analysis that are directly related to wind energy development. The first concerns cumulative effects on a population over time. That is, are effects (positive or negative) caused by the wind facility relatively subtle over a short period of time, so that only a longer-term study will reveal the trend of impact? This impact could theoretically apply to the wildlife in and immediately around the wind facility, or could manifest itself in the demographics of populations or subpopulations some distance away through changes in immigration and emigration. This type of influence is extremely difficult to quantify in the field without a tremendous expenditure of time and funds and is typically not expected to occur as a result of a single wind project. Here, it becomes essential that a rigorous and focused modeling framework be established so that the potential impacts can be hypothesized given a variety of scenarios (e.g., levels of death and habitat loss). In this way, inference can be drawn from data collected over the short term at multiple projects as it applies to likely longer-term impacts using projections of various population and habitat models.

The second issue with regard to cumulative effects concerns the expansion of an existing wind facility. The comments in the preceding paragraph still apply, but the issue is complicated by the continuing development of the wind facility. No information is available on how wildlife populations respond to wind facility expansion. In particular, we do not know if the relationship between number of turbines and number of deaths is linear, or if it plateaus at some point. We also do not know the demographic effects of habitat loss and fragmentation. Further, we do not know if the potential benefits of a wind facility to certain species (e.g., potential increase in prey for raptors) reaches some optimal level given a certain size of the wind facility. Here again, the most efficient approach would be to model the likely responses of a population to simulated changes in prey abundance, deaths, and reproduction and then compare the resulting population with what is found initially in the field. These results will indicate the level of concern that should be applied to wildlife deaths and habitat loss.

Proper experimental designs must be implemented for analysis of the response of wildlife to wind energy development. It is beyond the scope of this chapter to describe all of the various designs and analyses possible and this subject is dealt with in more detail in Appendix C. The standard call for adequate treatments and references, including pre-treatment data, apply to cumulative effects studies. The advantage of designing a study of cumulative effects as a wind facility expands is that good references potentially exist in the areas that are scheduled for development at some point in the future. The only weakness here is that, if the wind facility is fully developed, the references will eventually disappear; allowances should be designed for this eventuality. For example, at the wind facility at Buffalo Ridge, Minnesota, Johnson et al. (2000a) located a reference area that could be suitable for wind energy development, but was unlikely to be so developed.

Land uses unrelated to wind development also could impact wildlife populations inhabiting a wind facility. For example, residential housing, commercial development, roads, and agriculture could influence wildlife on or near a wind facility. It is not the purpose of this document, however, to discuss the myriad non-wind factors that could be part of a complete analysis of the cumulative effects of human activities on wildlife populations. Such an endeavor would involve a thorough environmental impact assessment. Nevertheless, these land uses should be considered when selecting reference areas and/or interpreting data from wind energy impact studies.

We will focus our discussion on bird mortality to illustrate some approaches and the difficulties in assessing cumulative impacts. The cumulative effects of a wind facility on a population over time could apply to the wildlife in and immediately around a wind project, or in a region with multiple wind projects, or could manifest itself in populations or subpopulations some distance away through changes in immigration and emigration. The cumulative effects resulting from the expansion of an existing wind facility or regional wind facilities are extremely difficult to quantify in the field without a tremendous expenditure of time and funds. Establishing a rigorous and focused modeling framework becomes essential for hypothesizing the potential impacts given a variety of scenarios. In this way, inference can be drawn from data collected over the short term as it applies to likely longer-term impacts using projections of various population models.

No wind energy facilities have been documented to cause population declines of any species, even the golden eagle population using the APWRA in California (Hunt 2002), where an estimated 40–70 golden eagles are killed each year (Hunt 2002, Smallwood and Thelander 2004). The likelihood of population level impacts on birds and bats from individual projects is very low. However, with the potential for large areas of development in various portions of the country, the concern over the cumulative impacts of wind development on birds and bats is high.

*Cumulative Impacts Case Study – Columbia Plateau Ecoregion*

The following example of the potential cumulative impacts of wind energy development is derived from a larger report on analysis of the potential cumulative impacts of existing and planned wind energy development in the Columbia Plateau Ecoregion (CPE) of eastern Washington and Oregon (Johnson and Erickson 2008). This analysis assumed that for cumulative impacts to occur there must be a potential for a long-term reduction in the size of a population of Swainson's hawk. When assessing the potential for cumulative impacts, it is necessary to first define the population potentially affected by wind energy development. Because birds and other animals do not recognize geopolitical boundaries, the affected population was Swainson's hawks that breed, winter, or migrate through the CPE.

The authors summarized results of 11 fatality monitoring studies at operational wind energy facilities within the CPE, and then used those results to estimate impacts for all constructed and proposed wind energy facilities within the CPE (Figure 5.5). Habitat and land use throughout the entire CPE are relatively similar with the predominant land use being a mosaic of agriculture – mainly dry land wheat farming, and grassland or shrub-steppe rangeland used for livestock grazing. In general, the region where future wind energy facilities are being planned is similar in vegetation types (Quigley and Arbelbeide 1997), although, for any given facility, the amount of each type varies.

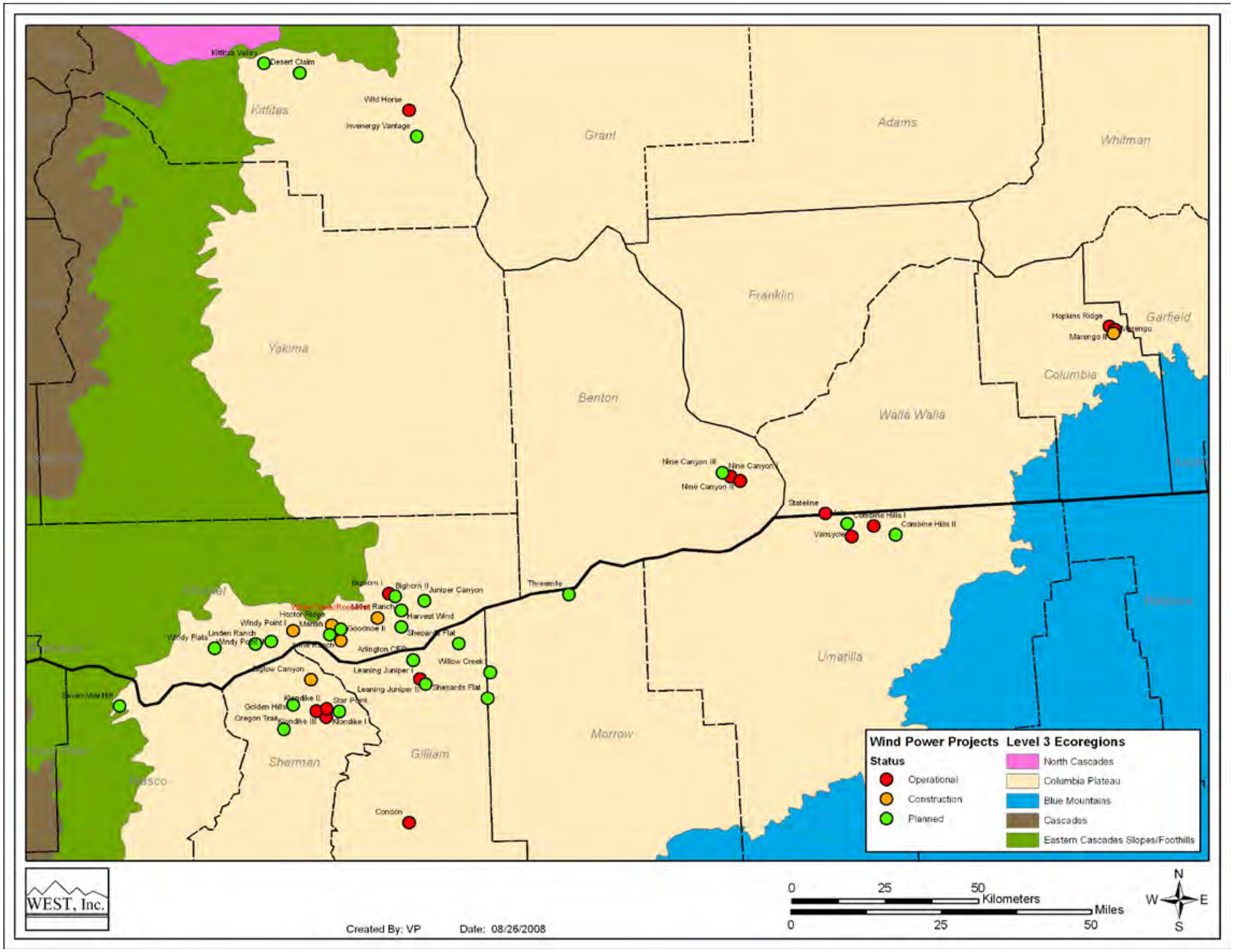


**Figure 5.5. Location of existing and proposed wind-energy facilities in the Columbia Plateau Ecoregion of southeastern Washington and northeastern Oregon (Johnson and Erickson 2008).**

To define population sizes of Swainson's hawk, the authors used data from a recent publication that estimated breeding population size of bird species by Bird Conservation Region, and then by that portion of each state within the Bird Conservation Region (see Blancher et al. 2007). The Great Basin Bird Conservation Region (see United States North American Bird Conservation Initiative [NABCI] Committee [2000] for a description) essentially occupied the same area within Washington and Oregon as the CPE. Habitat and land use throughout the entire CPE are relatively similar, with the predominant land use being a mosaic of agriculture, mainly dryland wheat farming, and grassland or shrub- steppe rangeland used for livestock grazing.

Pre-construction raptor use estimates and post-construction raptor fatality estimates were available for 11 facilities in eastern Washington and Oregon (WEST Inc., unpublished data). Raptor use (raptors/survey) at WRAs in the CPE ranges from 0.26 to 1.64, and averages 0.68 observations per 20-min survey. To predict raptor mortality for all existing and proposed wind energy facilities in the CPE, the authors assumed it would be similar to the other existing wind energy facilities in the CPE. Mean annual raptor mortality (fatalities/MW/year) at the 11 existing wind energy facilities in eastern Washington and Oregon ranges from 0 to 0.15/MW/year, with a mean of 0.07/MW/year.

Because the 1.5-3.0 MW turbines constructed or proposed for most new-generation wind energy facilities are larger than turbines used at most of the existing facilities, it is likely not appropriate to predict raptor mortality in the CPE using per turbine estimates from the other wind energy facilities, as several of the existing facilities used smaller turbines, ranging from 0.66-1.5 MW in size. Therefore, the authors used per megawatt estimates of raptor mortality for extrapolating the estimated numbers of raptor fatalities in the CPE. They used a range of 0.07 (mean) to 0.15 (maximum) raptor fatalities/MW/year to estimate raptor mortality at each of the CPE wind energy facilities. To estimate cumulative mortality of Swainson's hawk, the authors assumed that species composition of bird and bat fatalities associated with 6,700 MW of wind energy would be similar to species composition of fatalities found at the 11 existing facilities in the CPE (Johnson and Erickson 2008).

Using raptor mortality estimates from existing wind energy facilities in the CPE, the authors estimated that the future total annual raptor mortality in the CPE would be 469 fatalities, with an upper bound of 1,005. The upper bound assumes that all projects would have raptor fatality rates similar to those experienced at the wind facility with the highest raptor mortality rate (0.15/MW/year), which is unlikely. Swainson's hawks have composed 5.3% (three of 57 fatalities) at existing facilities; assuming a total of 469 raptor fatalities could occur each year in the future in the CPE, 25 Swainson's hawk fatalities would occur per year.

The estimated Swainson's hawk breeding population in the CPE is 10,000 (Blancher et al. 2007). Swainson's hawks occur in the CPE only during summer and most are resident breeders. Given the mortality estimate of 25 Swainson's hawks per year, this would represent 0.25% of the Swainson's hawks in the CPE.

### Study Design for Risk Reduction

Individuals from the wind industry and the scientific community as well as individual environmentalists and regulators have postulated that bird deaths can be reduced by modifying turbines to deter perching by birds, painting disruptive patterns on turbine blades, modifying turbine spacing, and so on. Some have suggested, however, that statistically valid analyses of such treatments are not feasible because bird death appears to be such a rare event. While it may be argued that simply reducing bird use on and around turbines is sufficient to conclude that treatments have been effective, the weakness of this argument is that changes in behavior could also cause increases in death even if the use around turbines has declined. (For example, a perch guard might successfully prevent birds from perching on the tower, but might also have the effect of causing a frightened bird to fly into the blades, indirectly resulting in the very death it was designed to prevent.) Further, without quantification of dead birds, no statements can be made regarding the influence of turbines on the abundance and dynamics of bird populations – unless the turbines displaced the population (see Chapter 3). If the risk to an individual per visit to a turbine stays the same, then mortality (rate of bird death) has not been reduced even if fewer birds visit. Thus, the parameter used to quantify "visit" is an absolutely critical part of impact assessment.

The evaluation of pre-construction risk-reduction measures for birds and bats will normally occur as a result of fatality studies. However, when fatalities are unexpectedly high after a project is in operation, additional risk-reduction measures may be required. Developing these risk-reduction measures frequently requires detailed study to evaluate existing potential alternatives, or to develop new risk-reduction measures. The following discussion focuses on the typical risk-reduction measures and provides suggestions on how to develop and evaluate new measures.

*Facility Siting*
It seems intuitive that wind developers can reduce risk of avian fatalities or significant habitat impacts by avoiding areas of concentrated activity of birds known to be at risk for collisions when siting facilities (macro-siting). Site assessment and baseline studies can be used to determine if a proposed facility site is located in areas of high nesting or seasonal density, or in the range of a threatened or endangered species. While using data from the site assessment and baseline studies can potentially reduce the absolute number of bird deaths, the success of these measures in reducing fatalities should be evaluated through fatality and habitat impact studies.

**On-Site Reduction of Risk**

There are two major possibilities for reducing the risk to birds on a developing site. First, risk can be reduced by placing individual turbines and support facilities in areas of low avian use (micrositing); and second, the site can be made unsuitable for use by birds or a specific bird species through changes in habitat parameters (e.g., changing prey type or abundance, removing potential perches within the facility).

Micrositing includes the siting of turbines away from areas where birds or bats concentrate, such as near roost, perch and nest sites, near heavily used vegetated gullies or water sources, and near known hibernacula.

Birds and bats exhibit variations in activity both within and among days. These variations can be quantified by developing activity budgets for species of concern. Based on such data, reliable models could be developed that predict times of maximum risk to birds and bats. However, it is important to recognize that development of a wind facility may change prey availability to birds and bats, both increasing food for certain species and decreasing it for others. For example, at the APWRA it appears that numbers of California ground squirrels (*Spermophilus beecheyi*) increased because of soil disturbance and decreased grass height due to vegetation management that often accompanied wind facility development and maintenance. Because squirrels are a central part of the diet of many large raptors, it is likely that this increase in squirrel abundance attracted raptors, especially golden eagles and red-tailed hawks, to the site. Hunt (2002) hypothesized that this increased abundance of prey was at least partially responsible for the relatively high eagle fatalities at APWRA. Thus, this increase in prey apparently increased risk to raptors at APWRA.

## Basic Experimental Approaches for Risk Reduction

As outlined by Mayer (1996), there are four tasks that the investigator must accomplish when designing a study of wind energy/bird interactions. The logic is sequential and nested; each choice depends on the previous choice:

1. ***Isolate the hypothesis of mechanism that is being tested.*** For example, one might be testing the hypothesis that birds strike blades and are either injured or killed (injury-death) when attempting to perch on a turbine.
2. ***Choose a measure of injury-death frequency that best isolates the hypothesis being tested.*** The two components of this choice are to choose an injury-death count to use as a numerator and a base count (likely utilization) to use as a denominator. It is critical that a relevant measure of use be obtained (e.g., passes through the rotor plane; occurrence by flight-height categories; use within a certain distance of the turbine).
3. ***Choose a measure of effect that uses the measure of injury-death frequency and isolates the hypothesis being tested.*** The key is to decide whether the relative risk (risk ratio), attributable risk, or another measure of effect should be used.
4. ***Design a study that compares two or more groups using the measure of effect applied to the measure of injury-death frequency chosen.*** The goals here are to isolate the effect, control for confounding factors, and allow a test of the hypothesis. Replication is essential.

The ideal denominator in epidemiology is the unit that represents a constant risk to the bird. The unit might be miles of flight, hours spent in the site, or years of life. If the denominator is the total population number, then we are assuming that each bird bears the same risk by being alive. In human epidemiological studies, the total population size is usually used because we cannot estimate units of time or units of use. In wildlife studies, however, actual population density is extremely difficult to estimate and entire populations are seldom at risk from the site. If the risk is caused by being in the area, then deaths per hour in the area is probably the best epidemiological measure in wildlife studies. It is then extrapolated to the population by estimating the utilization rate of the area for the entire population. Measuring utilization is difficult, however, and must be approached carefully (see discussion of baseline studies). The metric for mortality or fatality rates is discussed in detail in Chapter 4.

## Designed Experiment

*Example Study Design*
A designed experiment in its simplest form requires a treatment and a control (Appendix C). For example, if one wishes to determine if blade painting as suggested by Hodos (2003) is effective in reducing bird fatalities within a facility, one could randomly assign treatments (blades painted with the Hodos design) and controls (standard blade painting). The sample size for this study is determined by the number of turbines selected for the study. However, if the goal is to assess if the Hodos design would be effective at all facilities within some geographic area, say all of California, then this study would need to be replicated at a sample of the facilities in California. In this case the sample size for statistical inference is the number of facilities. However, experiments can be much more complicated depending on the resources available to the

investigator. For example, facilities might be paired so that facilities in the desert are blocked, facilities in grasslands are blocked, and the allocation of treatments and controls are randomly assigned within each block. For a more detailed description of the design options, see Morrison et al. (2008).

*Case Study Approach*

Case studies have high utility in evaluating mortality. Here, one collects dead birds inside and outside a wind facility, and conducts blind analysis to determine the cause of death. Unfortunately, under most situations very few dead birds will be found outside the site.

The case study approach suggests that epidemiological analysis often can be combined with clinical analysis to extend the inferential power of a study. Here, the clinical analysis would be the necropsies of the birds. Suppose we are successful at finding dead birds inside a wind facility. If we look at *proportional mortality* – the proportion of the birds killed by blunt trauma, sharp trauma, poisoning, hunting, natural causes, etc. – then the proportions should differ significantly between the facility and the reference area. The assumption is that the differential bias in finding dead birds within the two areas is uniform across the causes of mortality and thus the proportions should be the same even if the counts differ (i.e., relatively few dead birds found outside the site).

## Behavioral and Physiological Studies

Obtaining information on the sensory abilities of birds and bats should help in designing potential risk-reduction strategies for wind facilities and individual turbines. Although it may seem intuitive to paint blades so birds can more readily see them, there are many possible designs and colors to select from. For example, what colors can birds see, and how do birds react to different patterns? If painting blades causes a bird to panic and fly into another turbine, then painting has not achieved its intended goal. It may also be intuitive that bats might be discouraged from coming near turbines if some device could be mounted on turbines that repel bats (E.B. Arnett, Bat Conservation International [BCI], pers. comm.). Many of these questions are best investigated initially in a laboratory setting. Unfortunately, translating lab findings to the field is an age-old problem in behavioral ecology. Success in the lab using tame and trained birds or bats does not necessarily mean success in the field, where a myriad of other factors come into play (wind speed and direction, fog, presence of other birds, variation in insect prey for bats), and the physical scales are different. However, initial lab studies can help to narrow the scope of field trials. A sequential process of initial lab testing of treatments, followed by field trials, followed by additional lab trials as indicated, can be implemented.

Researchers under the direction of Drs. Hugh McIsaac and Mark Fuller, Boise State University, and Dr. William Hodos, University of Maryland, conducted a series of intensive laboratory trials to determine the visual acuity of raptors (Hodos 2003, McIsaac 2003). Both investigative teams found that birds lose the ability to detect moving turbine blades due to motion smear when they approach within 3 m (10 feet) of the blades. Both teams included trials to determine the ability of the birds to differentiate between differently painted patterns on turbine blades. The McIsaac-Fuller research team initiated field trials to determine the ability of trained but free-flying raptors to avoid painted blades (McIsaac and Fuller, Boise State University, unpublished data). This research is an example of how combining laboratory and field experimentation can be conducted to address bird-wind interactions.

*Foote Creek Rim UV Paint Study: A Suboptimal Design*

At least 30 species of birds can see Ultra Violet (UV) light (see Bennett and Cuthill 1994). Most diurnal birds, including raptors, are probably able to detect UV light, a spectrum not detected by the human eye (Jacobs 1992), although nocturnal species are probably not able to discriminate between UV and other light spectra (Jacobs 1992). UV vision is potentially important for most aspects of a bird's life, including sexual selection, predator avoidance, foraging, orientation and migration. Painting turbine blades with UV reflective paint could potentially reduce bird collisions by making them more visible to birds.

Although the effectiveness of UV-reflective paint to reduce bird mortality had not been experimentally tested, during the permitting process for the initial construction phase of the Foote Creek Rim (FCR) Wind Plant in Carbon County, Wyoming, the USFWS recommended that the turbine blades be painted with a UV-light reflective paint in an effort to minimize avian collisions. Unfortunately, this measure was implemented by the project developer for all turbines in the first two phases of FCR (FCR I and FCR II) without consideration for a more rigorous control-impact study design to test its collision risk-reducing effectiveness. Once FCR III was constructed, the basis for a comparison study was established but without control over the spatial distribution of turbines with UV-reflective blades.

Young et al. (2003d) examined the effects on bird use and mortality of painting wind turbine blades with UV-reflective paint at the FCR I and II facilities. The primary objectives of the study were to: (1) review and critique published and unpublished information relevant to the study; (2) estimate spatial and temporal use and behavior of birds near turbines with blades coated with UV-reflective paint versus those coated with non-UV-reflective paint; and (3) compare the number of carcasses found near turbines that had blades coated with UV-reflective paint versus those coated with non-UV-reflective paint. Young et al. (2003d) evaluated the change in collision risk due to the treatment through measurement of avian behavior, use, and mortality within varying distances of turbines with and without the treatment (UV reflective paint) using standard statistical analyses for reference/impact designs.

Because turbine strings treated with UV paint were located in strings away from those not treated, the overall study format was a rather poor example of a quasi-experiment or observational study often referred to as an impact-reference design (Morrison et al. 2001). The impact-reference design is used for comparison of response variables measured on treated areas (area near UV turbines [UV area]) with measurements from reference areas (areas near non-UV turbines [non-UV area]). The impact-reference design was also chosen because relevant "before" construction data were not available for the areas near the turbines.

Relative use of the wind facility by avian species was measured through point-count surveys conducted at each station twice each survey day during daylight hours (Young et al. 2003d). Activity and behavior of each bird observed were recorded, as well as other parameters related to the risk of birds near turbines such as distance from a turbine, flight height, and group size. Mortality was measured through carcass searches of plots centered on turbines. Mortality estimates were adjusted for scavenger removal and searcher efficiency biases.

The data were analyzed to determine a change (increase or decrease) in risk due to the treatment (UV paint). This was evaluated through the measurement of avian use, observed fatality rates, and to the extent possible, behavior (as measured by flight characteristics) at turbines with and without the treatment using standard statistical analyses for impact-reference designs (Skalski and Robson 1992).

Avian use varied between the UV and non-UV turbine areas. Overall raptor use was significantly higher in the UV area (0.778/survey) compared to the non-UV area (0.215/survey). In contrast, passerine use did not differ between the UV and non-UV areas due mainly to the high abundance of horned larks across the whole rim (Young et al. 2003d).

There was no significant difference between observed mortality between the UV and non-UV turbines. Observed passerine mortality at UV turbines was two times higher than the non-UV turbines, but the difference was not statistically significant. The avian risk index, mortality divided by mean use, provides a relative measure of the risk of birds colliding with turbines. If there was no difference in the risk of collision between the UV and non-UV turbine areas, we would expect similar risk indices for both areas (i.e., fatalities would be proportional to use for both areas). A difference between the indices for the two areas would suggest a difference in risk of collisions between the two turbine types. There was no significant difference between the risk indices for different bird groups between the two areas. The risk index for raptors was approximately three times higher at the non-UV area, due to lower use estimates; however, this was not significantly different. Due to the small sample size of raptor fatalities (6), the magnitude of this difference was probably not reliably measured (Young et al. 2003d).

Avian behavior was addressed through observation of flight characteristics (e.g., distance from turbines). Qualitative observations of birds avoiding turbines were noted but not included in the analyses. There was no significant difference in raptor use in different distance bands from UV and non-UV turbines, suggesting that there was no difference in the propensity of raptors to fly closer to one turbine type (Young et al. 2003d).

Several alternative designs would have improved this study, even without before data. For example, the UV-reflective paint treatment could have been applied to random turbines within all three phases, or within Phase I and II, with Phase III turbines retained as a reference.

*Foote Creek Rim Raptor Risk Assessment*
In addition to modification of turbines and other wind energy infrastructure, another way to reduce or mitigate impacts is through careful siting of wind energy facilities as well as turbines within wind energy facilities. Within a given facility, avoidance of physical microhabitats used by raptors including swales, ridge tops, canyons, and rims would likely reduce collision risk (Howell and Didonato 1991; Orloff and Flannery 1996). For example, spatial use data were collected at the FCR, Wyoming wind energy facility starting five years prior to development. Foote Creek Rim is a tabletop mesa with abrupt, steep slopes along the east and west edges. Raptor use data indicated that raptors used the rim edge significantly more than other portions of the study area (Figure 5.6). For each raptor observation on Foote Creek Rim, locations were placed into one of three strata: (1) within 50 m of the rim edge; (2) >50 m off of the rim; and (3) over the mesa but >50 m away from the rim edge. A far greater proportion of raptors observed along the rim edge were flying at heights within the rotor-swept height (19 m-62 m) of the turbines than were birds flying away from the rim edge. Consistently greater use of the rim edge by all raptor groups combined with a tendency by raptors to fly within the rotor-swept height along the rim edge led to a recommendation that turbines be placed >50 m away from the rim edge to reduce risk to raptors at this site (Johnson et al. 2000b).

These high use areas were avoided by the wind power developer when turbines were sited. Anecdotally, the BLM (1995) considered golden eagle abundance at the FCR area prior to construction to be similar to the APWRA in California. Based on the assumption of similar densities, the BLM predicted fatality rates for the Foote Creek area similar to the APWRA, or approximately two golden eagle fatalities per year (BLM 1995). However, over a 3-year period, 133 turbines were searched for fatalities, for a total of 202 turbine search years, resulting in one golden eagle fatality (Young et al. 2003b). Micro-siting of turbines may partially explain why fatalities of golden eagle were lower than predicted at Foote Creek Rim.

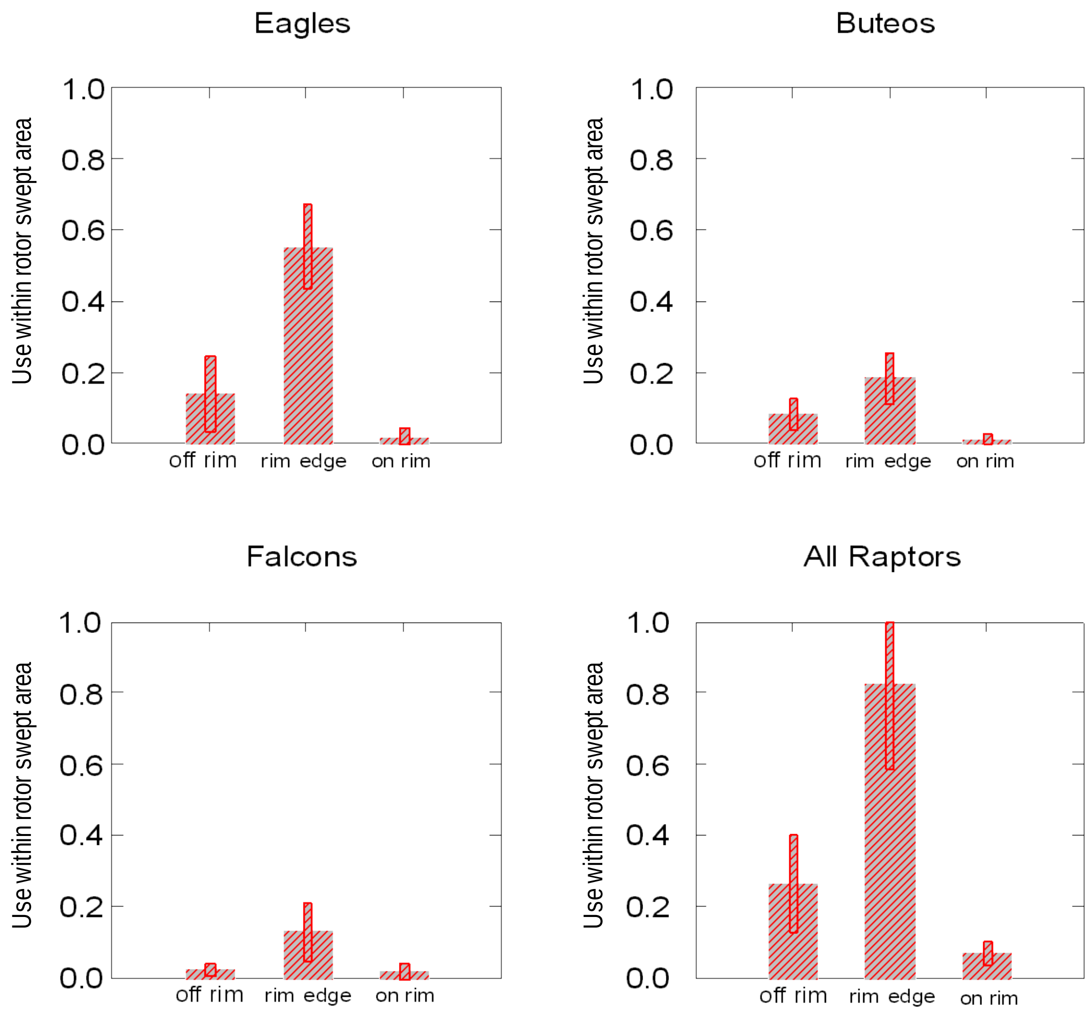


**Figure 5.6. Raptor use within rotor swept area in relation to the rim edge at the Foote Creek Rim project in Carbon County, Wyoming (from Johnson et al. 2000b).**

**Weather Associations with Bat Mortality**

In this case study from the Mountaineer wind project in West Virginia, Arnett et al. (2005) developed models to determine the association between nightly weather characteristics and high bat mortality nights.

Using weather and turbine characteristics (Table 5.1) from Meyersdale and Mountaineer, the authors fit several logistic regression models (Ramsey and Schafer 1997) to predict relatively high bat fatalities versus low fatalities found at a site. The number of nights was used as the experimental unit. The total number of observations (i.e., nights), predictor variables, and the models analyzed were the same as those discussed above for multiple regression analyses for both Meyersdale and Mountaineer. A “best” set of predictor variables to include in the logistic model was selected by fitting all possible two predictor variables, and their interaction of predictor variables (i.e., one model was fit with the interaction term, and another model without) and ranking the resulting models by corrected Akaike’s Information Criterion (Burnham and Anderson 2002). The model with minimum $AIC_C$ among those fit was chosen as our “best” model given the data and the set of models fit (Burnham and Anderson 2002). In standard logistic regression analysis, individual “successes” (here, a high index of the number of fresh bat mortalities) and “failures” (here, a low index of the number of fresh bat mortalities) are assumed to be independent of one another and follow a binomial distribution. For inferences about each parameter in every model fit, they calculated the Wald’s $\chi^2$ statistic and p-value using standard statistical procedures for logistic regression models (Ramsey and Schafer 1997). All calculations were carried out using SAS Proc LOGISTIC (SAS Institute 2000).

**Table 5.1. Abbreviations and descriptions of weather and turbine variables used for analyses at the Mountaineer and Meyersdale Wind Energy Centers (Kerns and Kerlinger 2004, Arnett et al. 2005).**

| Abbreviation | Description |
|---|---|
| tet_avg | Mean nightly temperature; measured at turbines and averaged across all turbines at a site. |
| hum_avg | Mean nightly relative humidity; measured at met towers and averaged for all towers at a site. |
| pre_avg | Mean nightly barometric pressure; measured at met towers and averaged for all towers at a site. |
| wst_med, wst_avg | Median or average nightly wind speed; measured at turbines and averaged across all turbines at a site. |
| wsm_med, wsm_avg | Median or average nightly wind speed; measured at met towers and averaged across all turbines at a site. |
| pc2 | Proportion of night (10 min intervals) from 2000 to 0600 hr with wind speed of 0-4 m/s; measured at turbines and averaged across all turbines at a site. |
| pc4 | Proportion of night (10 min intervals) from 2000 to 0600 hr with wind speed of 4-6 m/s; measured at turbines and averaged across all turbines at a site. |
| pc6 | Proportion of night (10 min intervals) from 2000 to 0600 hr with wind speed of >6 m/s; measured at turbines and averaged across all turbines at a site. |
| rpm | Mean nightly turbine blade speed (rpm); measured at turbines and averaged across all turbines at a site. |
| r_s | Proportion of night when rain was recorded; categorical variable classed as <10% or >10% of night; data measured by National Weather Service in Morgantown, WV. |
| wst_med^2, wst_avg^2 | Quadratic term for median or average mean nightly temperature; measured at turbines and averaged across all turbines at a site. |
| bp_mean*2 | Quadratic term for mean nightly barometric pressure; measured at met towers and averaged for all towers at a site. |

*Results*

Wind speed and weather were significantly related to predicting a high or low bat fatality night. Nights with higher wind speeds and storms/rain had few fatalities, while nights immediately after storms/rain with low wind speeds had higher fatalities.

<u>Curtailment of Bat Fatality Case Study</u>

Arnett et al. (2009) implemented the first experiment in the United States on the effectiveness of changing turbine cut-in speed on reducing bat fatalities at wind turbines at the Casselman Wind Project in Somerset County, Pennsylvania. Their objectives included: (1) determine the difference in bat fatalities at turbines with different cut-in-speeds relative to fully operational turbines; and (2) determine the economic costs of the experiment and estimated costs for the entire project area under different curtailment prescriptions and timeframes.

Twelve of the 23 turbines at the site were randomly selected for the experiment (Arnett et al. 2009a). Three treatments were applied at each turbine with four replicates on each night of the experiment: (1) fully operational, (2) cut-in speed at 5.0 m/s, and (3) cut-in speed at 6.5 m/s. The study used a completely randomized design. Treatments were randomly assigned to turbines each night of the experiment, with the night when treatments were applied acting as the experimental unit. Daily searches were conducted at the 12 turbines from 27 July to 9 October 2008 and 26 July to 8 October 2009. During this same period, daily searches were conducted at 10 different turbines that acted as a '"control" to the curtailed turbines. The authors performed two different analyses to evaluate the effectiveness of changing turbine cut-in speed to reduce bat fatalities. In the one analysis, they used 12 turbines to determine differences in fatality between curtailment levels. In the second analysis, they used 22 turbines to determine differences in fatalities between curtailment and fully operational turbines. The experimental unit in the first analysis was the turbine-night, and turbines were considered a random blocking factor within which all treatments were applied. In the first analysis, the total number of fatalities from the previous night (herein referred to as "fresh" fatalities) in each treatment at each turbine was modeled as a Poisson random variable. For the second analysis, the turbine was the experimental unit, with 12 turbines receiving the curtailment treatment, and 10 turbines as the control (fully operational at all times). They used all carcasses found at a turbine to estimate the total number of bat fatalities that occurred at each turbine between 27 July and 9 October 2008 and 26 July to 8 October 2009 and compared fatalities using one-way ANOVA (Arnett et al. 2009a).

There was strong evidence that the estimated number of fatalities over 25 nights differed among turbine treatments. The authors demonstrated nightly reductions in bat fatality ranging from 52-92% in 2008 and 44-86% in 2009 with marginal annual power loss (Arnett et al. 2009a). Total fatalities at fully operational turbines were estimated to be 5.4 times greater on average than at curtailed turbines in 2008 and 3.6 times greater on average than at curtailed turbines in 2009. The lost power output resulting from the experiment amounted to approximately 2% of total project output during the 75-day study period for the 12 turbines (Arnett et al. 2009a). Hypothetically, if the experimental changes in cut-in speed had been applied to all 23 turbines at the Casselman site for the study period (0.5 hour before sunset to 0.5 hour after sunrise for the 75 days of study), the 5.0 m/s curtailment used would have resulted in lost output equaling 3% of output during the study period and only 0.3 % of total annual output. If the 6.5 m/s curtailment were applied to all 23 turbines during the study period, the lost output would have amounted to 11% of total output for the period and ~1% of total annual output. In addition to the lost power revenue, the company also incurred costs for staff time to set up the processes and controls and to implement the curtailment from the company's offsite 24-hour operations center.

## Model-Based Analysis

Modeling is defined as the mathematical and statistical processes involved in fitting mathematical functions to data. Given this definition, models are included in all study designs. The importance of models and assumptions in the analysis of empirical data ranges from little effect in design-based studies to being a critical part of data analysis in model-based studies. Design-based studies result in predicted values and estimates of precision as a function of the study design. Model-based studies lead to predicted values and estimates of precision based on a combination of study design and model assumptions often open to criticism. Here, we briefly review the use of models in studies of wind-wildlife impacts (see Appendix C for more details on models and model based analysis).

Pure design/data-based analysis often is not possible in impact studies. For example, bird abundance in an area might be estimated on matched pairs of impacted and reference study sites. However carefully the matching is conducted, uncontrolled factors always remain that may introduce too much variation in the system to allow one to statistically detect important differences between the assessment and reference areas. In a field study, there likely will be naturally varying factors whose effects on the impact indicators are confounded with the effects of the incident. Data for easily obtainable random variables that are correlated with the impact indicators (covariates) will help interpret the gradient of response observed in the field study. These variables ordinarily will not satisfy the criteria for determination of impact, but can be used in model-based analyses for refinement of the quantification of impact (Page et al. 1993).

For example, in the study of bird use at the FCR facility, WEST Inc. (1995) developed indices to prey abundance (e.g. prairie dogs, ground squirrels, and rabbits). These ancillary variables are used in model-based analyses to refine comparisons of avian predator use in assessment and reference areas. Land use also is an obvious covariate that could provide important information when evaluating differences in bird use among assessment and reference areas and time periods. Indicators of degree of exposure to the impact-producing factor also should be measured on sampling units. As in the Impact-Gradient Design, a clear impact-response relationship between impact indicators and degree of exposure will provide corroborating evidence of impact. These indicators also can be used with other concomitant variables in model-based analyses to help explain the noise in data from natural systems. For example, the size of turbines, the speed of the turbine blades, the type of turbine towers, etc. can possibly be considered indicators of the degree of exposure.

In many model-based analyses of populations, a central part of impact assessment is development of a model predicting the survival rates required to maintain a population. The strategy is to determine survival rates required to sustain populations exhibiting various combinations of the other parameters governing population size. To be useful in a wide range of environmental situations and useable for people with varying expertise, the model should be based on simple mathematics.

Morrison and Pollock (1997) sought to develop a useful, practical modeling framework for evaluating potential wind power facility impacts that can be generalized to populations of most bird species by: (1) reviewing the major factors that can influence the persistence of a wild population; (2) briefly reviewing various models that can aid in estimating population status and trends, including methods of evaluating model structure and performance; (3) reviewing survivorship and population projections; and (4) developing a framework for using models to evaluate the potential impacts of wind development on birds. Based on their review, Morrison and Pollock (1997) concluded that the appropriate hierarchical framework for evaluating population responses to perturbations is: (1) empirical data, (2) surrogates, and (3) models with available data (Leslie matrices). A large set of empirical data is, of course, the optimal situation. Several of the case studies previously presented in this chapter had model components, and some of the case studies were almost entirely model based. For our last case study we provide an example of a model-based approach to the evaluation of the impact of wind energy development on golden eagles.

**The Golden Eagle in the APWRA – A Case Study of a Demographic Study**

The impact of the APWRA on the resident golden eagle population has been under investigation for decades. During 1994–2000, the ecology of golden eagles was studied in west-central California, a region containing a higher reported density of breeding pairs than elsewhere reported. The work (see Hunt 2002, Hunt and Hunt 2006) centered on estimating whether wind turbine blade-strike fatalities at the APWRA were causing the local breeding population of eagles to decline. To address the question of impact upon the eagle population, 257 eagles of four life-stages were radio-tagged and monitored for movements and survival in the 9,000 $km^2$ study area over the 7-year period. The turbine blades accounted for 42 of 100 fatalities of radio-tagged eagles recorded during the study, and the actual number of strike deaths within the sample of tagged eagles was likely higher because the blades destroyed the transmitters in an unknown proportion of cases. Vital rate estimates of reproduction and survival were used within a standard age-based growth (trend) model to estimate the potential growth rate (*lambda*) of the population. The resulting estimate of the potential growth rate (lambda) was centered on 1.0, predicting neither increase nor decline in the population. However, if the point estimate of population growth represented its true value, then few locally-produced floaters would exist to fill breeder vacancies (Hunt 2002). Stability in the breeding segment might therefore require a supply of immigrant floaters from outside the core study area ( ≥ 30 km radius from APWRA). Using a Lefkovitch stage-based model, Shenk et al. (1996) concluded, however, that the trend in the eagle population was declining.

An example of mixing design- and model-based research is the project completed by Smallwood and Neher (2004). They used field data collected at the APWRA to relate raptor flight patterns to landscape attributes derived from a slope curvature analysis based on a digital elevation model of the landscape and ArcMap geo-processing tools, combined with wind directions recorded during the behavioral observation sessions. This data- and model-based approach allowed them to test hypotheses related to factors causing bird movements and subsequent mortalities. Based on their results, they recommended that locating new or relocating existing wind turbines on the prevailing leeward aspect of ridges and hills should result in reduced encounter frequencies between flying raptors and wind turbines; this hypothesis could then be tested in the field.

## ADAPTIVE MANAGEMENT

Adaptive management (AM) is a series of scientifically driven management actions (within economic and resource constraints) that use monitoring and research results to test competing hypotheses related to management decisions and actions, and apply the resulting information to improve management. AM can be categorized into two types: “passive” and “active” (Walters and Holling 1990, Murray and Marmorek 2003). In passive AM, alternatives are assessed and the management action deemed best is designed and implemented. Monitoring and evaluation then lead to adjustments as necessary. In active AM, managers explicitly recognize that they do not know which activities are best, and then select several alternative activities to design and implement. In active AM, monitoring and evaluation of each alternative helps in deciding which alternative is more effective in meeting objectives, and adjustments to the next round of management decisions can be made based on those lessons.

The iterative approach employed in this guide is similar to a passive AM decision-making process. In the pre-construction environment, analysis and interpretation of information gathered at a particular stage influences the decision to proceed further with the project or the project assessment. If the project is constructed, information gathered in the pre-construction assessment guides possible project modifications, or the need for and design of post-construction studies. Clearly, active AM is not feasible for siting decisions. However, analysis of the results of post construction studies can test design modifications and operational activities to determine their effectiveness in avoiding and minimizing impacts. When there is considerable uncertainty over the appropriate mitigation for a project, active AM is the preferred approach to testing the effectiveness of alternative approaches (Walters and Holling 1990, Murray and Marmorek 2003).

However, in the classic sense AM most often will be used in the context of studies of risk reduction and other forms of mitigation. That is, when there is uncertainty regarding which measures will be most successful in reducing risk or offsetting impacts, AM is an effective approach to reducing this uncertainty. For AM to work, there must be agreement to adjust management or mitigation measures if monitoring indicates that goals are not met.

## SUMMARY

Below is a summary of the primary points discussed in this chapter.

1. *Manipulative studies* can be an effective means of determining the response of wildlife to treatments or experiments designed to test behavioral responses to wind energy development.
2. Developing a *sound modeling framework* may help identify the critical aspects of the population that should be studied, even if a formal model is not calculated.
3. Quantification of habitat use with and without the project*,* including factors such as food abundance and access to brood-rearing habitat, can be an important part of evaluation of a population's status. When habitat loss is a concern, documenting the magnitude of habitat lost and quantifying the area of influence of a wind facility can help in the decision to expand an existing facility, in the design of future facilities, and in the mitigation of existing habitat impacts.
4. Cumulative habitat impacts are a concern for some wildlife populations; they are quantifiable and should consider the effects of other wind energy facilities as well as other forms of development and land use.
5. Population and cumulative impacts are difficult to study, and attribution of population effects from fatalities and habitat loss must consider mortality, reproduction, emigration and immigration.
6. In many situations, quantification of adult survivorship is an essential step in determining the status of the population of interest. Data on survival published in the literature are adequate to allow broad generalizations to be made regarding "adequate" survival for population maintenance.

7. Determining the spatial structure of a population – whether it is divided into subpopulations – is important in that it places the status of various life history parameters into context and assists in identifying key habitat components that may be impacted by a wind energy project.
8. Quantifying reproductive output and breeding density, when combined with knowledge of the population's spatial structure, provides a good idea of the status of the population. This will be especially important when adult survivorship cannot easily be determined.
9. It is likely that Leslie matrix models will be most useful when predicting the response of locally abundant subpopulations, where enough individuals are present for a population trend to be estimated.
10. Determination of the effective population size ($N_e$) likely will be useful in evaluating the status of rare subpopulations. A rapid determination of the likely lower critical threshold for the subpopulation is necessary.
11. Risk reduction studies are best conducted through use of a manipulative study design in an AM framework.
12. The study of impacts to habitat and populations should follow good experimental design principles with an emphasis on the optimum study designs when possible. Because most studies of wind energy impact are observational, cause and effect are difficult to establish, and the use of control and treatment structures offers the best opportunities to infer cause and effect relationships.

## DECISION PROCESS

The decision process at the end of post-construction studies is almost entirely based on how a facility will operate in the future given the outcome of the studies evaluating risk reduction and other mitigation. That is, if unacceptable impacts are confirmed through post-construction studies, including population impacts, in most cases additional efforts at risk reduction and other mitigation normally would follow. This results in an iterative process much like adaptive management where studies of impact are followed by studies of risk-reduction measures or other mitigation, followed by other studies evaluating additional attempts at reducing the uncertainty surrounding how to reduce risk or successfully mitigate for impacts that are unavoidable.

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# APPENDICES

# APPENDIX A – ASSESSING IMPACTS OF WIND-ENERGY DEVELOPMENT ON NOCTURNALLY ACTIVE BIRDS AND BATS: A GUIDANCE DOCUMENT

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*Invited Paper*

# Assessing Impacts of Wind-Energy Development on Nocturnally Active Birds and Bats: A Guidance Document

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**ABSTRACT** Our purpose is to provide researchers, consultants, decision-makers, and other stakeholders with guidance to methods and metrics for investigating nocturnally active birds and bats in relation to utility-scale wind-energy development. The primary objectives of such studies are to 1) assess potential impacts on resident and migratory species, 2) quantify fatality rates on resident and migratory populations, 3) determine the causes of bird and bat fatalities, and 4) develop, assess, and implement methods for reducing risks to bird and bat populations and their habitats. We describe methods and tools and their uses, discuss limitations, assumptions, and data interpretation, present case studies and examples, and offer suggestions for improving studies on nocturnally active birds and bats in relation to wind-energy development. We suggest best practices for research and monitoring studies using selected methods and metrics, but this is not intended as cookbook. We caution that each proposed and executed study will be different, and that decisions about which methods and metrics to use will depend upon several considerations, including study objectives, expected and realized risks to bird and bat populations, as well as budgetary and logistical considerations. Developed to complement and extend the existing National Wind Coordinating Committee document "Methods and Metrics for Assessing Impacts of Wind Energy Facilities on Wildlife" (Anderson et al. 1999), we provide information that stakeholders can use to aid in evaluating potential and actual impacts of wind power development on nocturnally active birds and bats. We hope that decision-makers will find these guidelines helpful as they assemble information needed to support the permitting process, and that the public will use this guidance document as they participate in the permitting processes. We further hope that the wind industry will find valuable guidance from this document when 1) complying with data requirements as a part of the permitting process, 2) evaluating sites for potential development, 3) assessing impacts of operational wind-energy facilities, and 4) mitigating local and cumulative impacts on nocturnally active birds and bats. (JOURNAL OF WILDLIFE MANAGEMENT 71(8):2449–2486; 2007)

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**KEY WORDS** bats, birds, methods, metrics, migration, wind energy.

Wind energy is one of the fastest growing sectors of the energy industry (Pasqualetti et al. 2004, National Research Council [NRC] 2007), a relatively recent development that has led to unexpected environmental consequences (Morrison and Sinclair 2004, Manville 2005, Kunz et al. 2007). The large number of raptor fatalities discovered at Altamont Pass in California in the early 1980s triggered widespread concern from environmental groups and wildlife agencies about possible impacts to bird populations (Anderson and Estep 1988; Estep 1989; Orloff and Flannery 1992, 1996). Anderson et al.'s (1999) comprehensive review and analysis of methods and metrics for the study of impacts of wind-energy facilities on birds provided valuable guidelines for assessing diurnally active wildlife but offered limited guidance on methods for assessing impacts on nocturnally active birds and bats. Given the projected growth of the wind-energy industry in the United States and emerging concerns over possible cumulative impacts of wind-energy facilities on nocturnally active birds and bats (Government Accountability Office [GAO] 2005, Manville 2005, NRC 2007, Arnett et al. 2008), we developed this document to supplement the earlier methods and metrics document.

The methods and metrics we consider herein include those suitable for assessing both direct and indirect impacts of wind energy. Direct impacts of wind-energy facilities refer to fatalities resulting from night-flying birds and bats being killed directly by collisions with wind turbine rotors and monopoles. Indirect impacts of wind-energy development refer to disruptions of foraging behavior, breeding activities, and migratory patterns resulting from alterations in landscapes used by nocturnally active birds and bats. Direct and indirect impacts on birds and bats can contribute to increased mortality, alterations in the availability of food, roost and nest resources, increased risk of predation, and potentially altered demographics, genetic structure, and population viability (NRC 2007).

## LIMITS OF CURRENT KNOWLEDGE ABOUT IMPACTS ON NOCTURNALLY ACTIVE BIRDS AND BATS

### Songbirds

Songbirds are by far the most abundant flying vertebrates in most terrestrial ecosystems, and until recently have been

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among the most frequently reported fatalities at utility-scale wind facilities in the United States. In a review of bird collisions reported from 31 studies at utility-scale wind-energy facilities in the United States, Erickson et al. (2001) showed that 78% of carcasses found at wind-energy facilities outside of California were songbirds protected by the Migratory Bird Treaty Act (16 United States Code 703–712); among these, approximately half were nocturnal, migrating passerines. The number of passerine fatalities reported in other studies has ranged from no birds during a 5-month survey at the Searsburg Vermont Wind Energy Facility, Searsburg, Vermont, USA (Kerlinger 1997) to 11.7 birds per megawatt (MW) per year during a 1-year study at Buffalo Mountain Wind Energy Center, Anderson County, Tennessee, USA (Nicholson 2003). Given the increasing number of installed and proposed wind-energy facilities, the relatively large number of passerine fatalities at wind-energy facilities on forested ridge tops in the eastern United States, such as Buffalo Mountain Wind Energy Center, Anderson County, Tennessee, and the Mountaineer Wind Energy Center, Tucker County, West Virginia has raised concern regarding the potential risk to nocturnally active songbirds (Kerns and Kerlinger 2004, GAO 2005, Fiedler et al. 2007, NRC 2007, Arnett et al. 2008).

### Bats

Recent monitoring studies indicate that utility-scale wind-energy facilities in the continental United States have killed considerably more bats than were expected based on early monitoring studies where birds have been the primary focus of attention (NRC 2007). Large numbers of bats have been killed at wind-energy facilities constructed along forested ridge tops in the eastern United States (GAO 2005, Kunz et al. 2007, NRC 2007, Arnett et al. 2008). The highest fatality rates at these facilities have ranged from 15.3 bats/MW/year at the Meyersdale Wind Energy Center, Somerset County, Pennsylvania to 41.1 bats/MW/year at the Buffalo Mountain Wind Energy Center (Fiedler 2004, Kunz et al. 2007, NRC 2007, Arnett et al. 2008). A recent follow-up study conducted at the Buffalo Mountain site reported fatality rates of 53.3 bats/MW/year at 3 small (0.66-MW) Vestas V47 wind turbines (Vestas Wind Systems A/S, Ringkøbing, Denmark) and 38.7 bats/MW/year at 15 larger (1.8-MW) Vestas V80 turbines (Fiedler et al. 2007). Another recent study, conducted at the Maple Ridge Wind Power Project, Lewis County, New York, USA estimated bat fatalities ranging from 12.3 bats to 17.8 bats/MW/year (depending on carcass search frequency) at 1.65-MW Vestas wind turbines (Jain et al. 2007). Bat fatalities reported from most other regions of the United States have ranged from 0.8 bats to 8.6 bats/MW/year, although these estimates were largely based on studies designed to estimate bird fatalities (but see Johnson et al. 2003, 2004, 2005). In addition to these fatalities, bats have been killed at wind-energy facilities located in agricultural areas of southwestern Alberta, Canada (Barclay et al. 2007), and in a mixed woodland–shrub–grassland landscape in north-central Oklahoma, USA (Piorkowski 2006). Little is known, however, about potential risks and fatalities in other regions in North America where wind-energy facilities are being developed at an unprecedented rate.

### Challenges to Impact Assessment and Prediction

Predicting impacts on bird and bat populations based on fatalities reported from existing wind facilities presents several challenges. Lack of reliable correction factors for biases associated with searcher efficiency and scavenging make it difficult to derive reliable estimates of fatalities for a given site or season, let alone to compare results from different regions and years to confidently predict cumulative impacts (Kunz et al. 2007, NRC 2007, Arnett et al. 2008). Several studies using radar have been conducted during preconstruction periods in efforts to estimate potential risks to nocturnal migrants. However, to date, none have provided sufficient evidence to reliably predict actual risk. In part, this may reflect the fact that existing sites typically have different ecological characteristics both before and after development (e.g., undisturbed forested ridge top vs. cleared ridge top with installed wind turbines).

*Bias correction factors.*—Scavengers are known to remove bird and bat carcasses before researchers are able to discover them and, thus, fatality rates will most likely be underestimated unless reliable estimates of scavenging rates are developed and applied to observed fatalities (Morrison 2002). Bias correction factors also are needed to adjust fatality estimates for searcher efficiency. For example, a study in West Virginia used test subjects (fresh and frozen bats or birds) to evaluate searcher efficiency and found that, on average, only about half of the animals were found by human observers (Arnett 2005, Arnett et al. 2008). Moreover, bats killed by wind turbines were twice as likely to be found by human observers in grassland areas compared to those in agricultural landscapes and along cleared forested ridge tops. In a recent study, trained dogs were able to find 71% of the bat carcasses during searcher-efficiency trials at the Mountaineer site in West Virginia and 81% at the Meyersdale site in Pennsylvania, compared to 42% versus 14%, respectively, for human searchers (Arnett 2006).

*Causal mechanisms of impact.*—Cooperation of the wind-energy industry is needed to help researchers develop a better understanding of how birds and bats interact with wind-energy facilities and to help identify the causal mechanisms of impact (Kunz et al. 2007, NRC 2007). Research and monitoring studies are needed to assess activities and abundance of birds and bats 1) before construction (e.g., before forests have been cleared and linear landscapes have been created); 2) after turbines have been installed (but before they become operational); and 3) after they have become operational, to test hypotheses needed to assess impacts of wind-energy facilities on birds and bats (Kunz et al. 2007, NRC 2007).

Results of such research could help researchers identify and the wind industry implement mitigation measures to avoid or minimize impacts on nocturnally active wildlife at existing facilities. For example, studies using thermal infrared imaging (Horn et al. 2008) and evidence from bat carcasses recovered at the Mountaineer and Meyersdale Wind Energy Centers in 2004 (Arnett 2005, Arnett et al. 2008) indicate that most fatalities occurred at times of low wind speeds (typically <6 m/sec), conditions under which rotor blades are moving but the amount of electricity generated is minimal (NRC 2007). These data suggest that a first-order priority should be to test the hypothesis that bat fatalities could be markedly reduced by mechanically feathering turbine blades (i.e., electronically pitching the blades parallel to the wind, effectively making them stationary) at low wind speeds (Kunz et al. 2007, Arnett et al. 2008).

Well-designed before-after-control impact (BACI) and comparative studies, and those that test responses of birds and bats to different operational conditions, are needed to fully evaluate options for mitigating fatalities to birds and bats at wind-energy projects (Kunz et al. 2007, NRC 2007). In this context, some success has been achieved with the installation of new turbine designs (e.g., lattice towers replaced with monopoles and fewer and taller turbines), and by testing visual deterrent by using different colors on turbine blades (Hodos 2003). A current study is underway to test the efficacy of acoustic deterrents (E. B. Arnett, Bat Conservation International, unpublished data).

We summarize methods for assessing risks to birds and bats associated with proposed and operational wind-energy facilities. A number of methods are available to observe nocturnal activities of birds and bats, including: night-vision observations, thermal infrared imaging, radar monitoring, acoustic recordings, and radiotracking (telemetry). Other research methods, including direct capture, collection of tissue for stable isotopes and DNA analysis, estimates of population size and genetic structure, and fatality assessments, provide critical information needed to assess direct, indirect, and cumulative impacts.

## METHODS AND METRICS FOR OBSERVING NOCTURNAL BEHAVIOR OF BIRDS AND BATS

Current understanding of where, when, how, and why bats and nocturnally active birds come into contact with wind turbines is limited by our ability to observe how they behave near these structures. Answering some of the most basic questions requires careful observations with appropriate methods to assess the nocturnal and seasonal timing of flight behavior of birds and bats in the vicinity of proposed and operating wind turbines. No single method or protocol can be used to unambiguously assess temporal and spatial variation in natural populations or the impacts of wind turbines on nocturnally active birds and bats. Each device or method has its own strengths, limitations, and biases, and the selection and application of one or multiple methods will depend on the specific objectives to be addressed. Sufficient information should be acquired to enable researchers to meet the stated goals of a proposed study. To avoid misinterpreting results, assumptions and limitations of each method must be explicitly acknowledged and evaluated (e.g., Hayes 2000, Gannon et al. 2003). Moreover, individuals charged with monitoring the activities of birds and bats must be thoroughly familiar with the operation and limitations of each method or device before initiating field studies.

### Visual Methods for Monitoring Nocturnal Activity

Making meaningful visual observations requires not only selecting the appropriate methods and equipment (Allison and De Stefano 2006), but it is essential that temporal and spatial scales of observations also be included to answer relevant questions.

*Moon watching.*—Early investigators used a moon-watching technique during full-moon periods with clear skies to observe migratory birds (Lowery 1951, Lowery and Newman 1955). By directing a telescope of sufficient power (20–30×) toward the full moon during periods of migration, it is possible to observe silhouettes of birds and bats as they pass before the illuminated disc of the moon. The primary limitation of this method is that sampling conditions are limited to cloudless nights with a full moon.

*Ceilometry.*—Given the limitations of moon watching, Gauthreaux (1969) developed a portable ceilometer to observe low-altitude nocturnal migrations on nights when the moon was not visible. This method employed an auxiliary light source (e.g., 100-W lamp) to illuminate a portion of the night sky that could then be sampled using binoculars or a spotting scope. This method has been used to detect large numbers of bird species flying ≤305 m above ground level (agl) with 7× binoculars, several bird species ≤457 m agl with a 20× telescope, and at detecting larger passerines (e.g., thrushes) ≤640 m agl with a 20× telescope (Gauthreaux 1969).

Able and Gauthreaux (1975) used a ceilometer to quantify the nocturnal migration of passerines, and expressed the magnitude of migration as the number of birds per 1.6 km of migratory front per hour, a metric derived from moon watching that also is currently used in some radar studies. Williams et al. (2001) used 300,000 candle power (Cp) spotlights instead of portable ceilometers for observing activity of thrush-sized passerines ≤500 m agl. The ability to detect airborne targets at night using artificial illumination diminishes with the square of distance from the observer and, thus, will depend on the intensity and effective range of the source of illumination.

Although ceilometers can provide information about relative traffic rates of nocturnal migrants, the beam of light samples a very small area relative to the available area potentially occupied by nocturnal migrants. Additionally, visible light from the ceilometer tends to attract birds and insects and, thus, can lead to biased results. This problem was recognized by Williams et al. (2001), where birds were observed around dim light scattered from the ceilometer. Estimates of flight altitude derived from this method also might be biased due to the greater probability of visually detecting lower flying birds and the general difficulty of visually estimating flight altitude. Detection biases associated with this method have not been objectively quantified.



**Figure 1.** Method for observing and recording activity of bats and birds at wind-energy projects using night-vision goggles and 2 supplementary light sources equipped with infrared filters (B. A. Cooper, Alaska Biological Research, Inc., unpublished data).

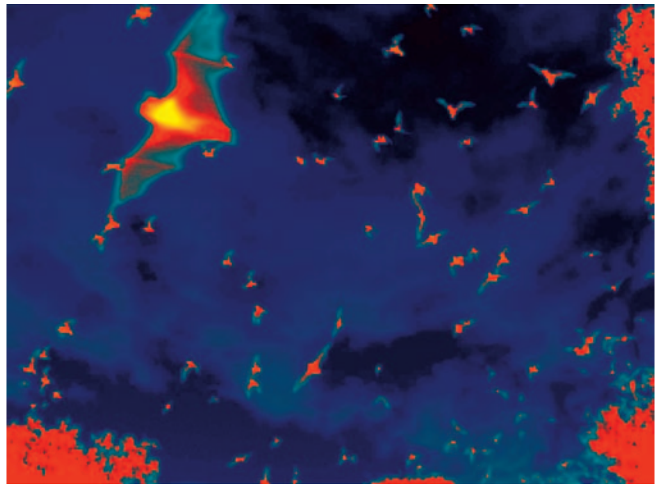

**Figure 2.** Thermal infrared image of foraging Brazilian free-tailed bats (*Tadarida brasiliensis*) in south-central Texas, USA. Warm bats are distinguished from the cooler background of clear sky and clouds (T. H. Kunz and M. Betke, Boston University, unpublished data).

*Night-vision imaging.*—Visual observations that employ night-vision goggles (NVG) and scopes, powerful (3-million Cp) spotlights, and reflective infrared cameras have greatly improved in recent years. Improvements of the NVG method over earlier visual methods include 1) greater freedom to follow and identify birds, bats, and insects; 2) use of both fixed and mobile spotlights that increase the ability to detect and identify animals correctly; and 3) infrared filters that eliminate the attraction of insects, birds, and bats to supplemental sources of visible light.

These improvements have made it possible to identify small birds and bats aloft at distances $\leq$150 m. Mabee et al. (2006*a*) used third-generation NVG with a 1× eyepiece (Model ATN-PVS7; American Technologies Network Corporation, San Francisco, CA), along with 2 3-million–Cp spotlights fitted with infrared filters to illuminate flying targets aloft at a planned wind-energy facility in New York state. Using this method, Mabee et al. (2006*a*) viewed the night sky through NVG and were able to track and identify moving targets using one stationary spotlight (mounted on a tripod with the beam oriented vertically) and a mobile spotlight (handheld with the beam parallel to the fixed spotlight's beam; Fig. 1).

For each bird or bat detected, flight direction, flight altitude, and flight behavior (e.g., straight-line, zig-zag, circling, hovering) often can be detected. Species identification, however, is rarely possible using this method. Video recordings of flight behavior can be recorded and analyzed repeatedly to determine how birds or bats respond to moving wind turbines. Metrics produced from NVG images include proportions of birds and bats observed flying at low altitudes ($\leq$150 m agl, the max. distance that passerines and bats can be discerned using this method), flight direction, and relative number of birds and bats observed per hour (standardized by estimating distance to targets if and when comparisons among studies are made).

Limitations of the NVG method include variable detectability of animals because of cloud cover, atmospheric moisture, and the effect of distance on detection. Night-vision devices, each of which contain photo-multiplier cells, also produce inherent visual noise, often making it difficult for observers to distinguish small birds from bats at night, even within the height of the rotor-swept zone of utility-scale wind turbines.

*Thermal infrared imaging.*—In contrast to night-vision technology, thermal infrared imaging cameras are designed to detect heat emitted from objects in a field of view without the need for artificial illumination. The metabolic heat produced by birds and bats (and some insects) produces a distinct image against a cooler background (Fig. 2). Typically, images can be captured at rates ranging from 30 frames to 100 frames per second (fps), depending on the camera, and digitally recorded to computer hard drives. Automated detection and tracking algorithms have been developed that may prove useful for assessing the behavior of birds and bats flying in the vicinity of wind turbines (Descholm et al. 2006, Betke et al. 2008).

Several studies have employed thermal infrared imaging cameras to observe movements of birds and bats flying near wind-energy facilities. Desholm (2003) and Desholm et al. (2004, 2006) used a long-wave (7–15 μm) thermal infrared camera (Thermovision IRMV 320V; Forward Looking Infrared [FLIR], Boston, MA), deployed as part of the Thermal Animal Detection System for automatic detection of avian collisions at an offshore wind-energy facility in Denmark. This system is triggered automatically when a target is detected and can be controlled remotely. In southwest Germany, Brinkmann et al. (2006) used a Mitsubishi Thermal Imager (IR-5120AII; Mitsubichi Electric Corporation, Kamakura, Japan) to observe bats in the vicinity of 2 wind turbines. This thermal camera operated at short wave lengths (3–5 μm) at 60 fps, and had a detector array consisting of 512 × 512 pixels, and with a 50-mm, F 1.2 infrared lens, provided a 14° × 11° field of

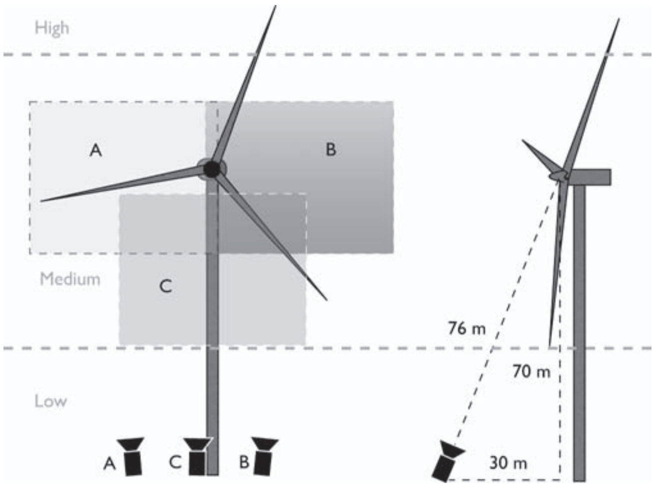


Figure 3. Configuration of 3 thermal infrared cameras for recording nightly observations of airborne targets (i.e., bats, birds, and insects) at the Mountaineer Wind Energy Center in Tucker County, West Virginia, USA. Cameras are positioned 30 m from the turbine base and pointed directly upwind and perpendicular to the plane of blade rotation. Observed bats, birds, and insects were classified into high, low, and medium categories corresponding to flight elevation above ground level (from Horn et al. 2008).

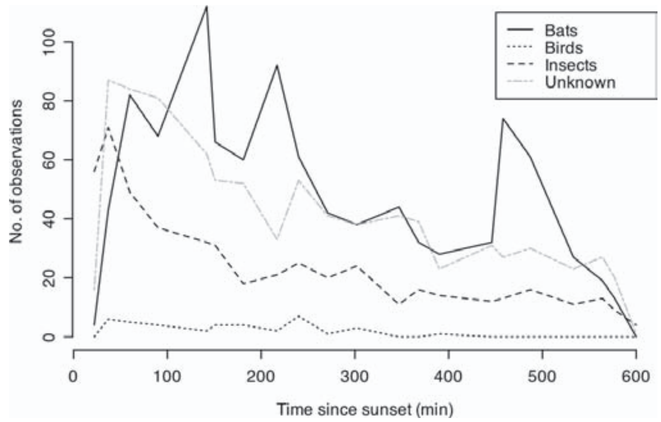


Figure 4. The distribution of activity during the night for bats, birds, insects, and unknown objects recorded with thermal infrared cameras from 2030 hours to 0530 hours at the Mountaineer Wind Energy Center, Tucker County, West Virginia, USA, August 2005 (from Horn et al. 2008).

view. With this system, flight patterns of bats could be distinguished at a distance of 100 m.

Liechti et al. (1995) used a long-range thermal imaging unit (Long Range Infrared System, IRTV-445L; Inframetrics, Nashua, NH) with a 1.45° telephoto lens and were able to detect nearly 100% of all small passerines within the field of view at a distance of 3,000 m. The same unit was used in Sweden to monitor autumn bird migration (Zehnder and Karlsson 2001, Zehnder et al. 2001) and in Africa, on the edge of the Sahara desert, to study nocturnal bird migration (Liechti et al. 2003). Gauthreaux and Livingston (2006) used a thermal imager (Radiance 1; Amber Raytheon, Goleta, CA) to study nocturnal migration at Pendleton, South Carolina, and Wallops Island, Virginia, USA, when weather conditions (no rain and relatively clear skies) allowed data collection. Daylight observations were made at McFaddin National Wildlife Refuge, Texas, USA. This thermal imaging camera, with a 100-mm lens, and a field of view of 5.57° (horizontal screen dimension) and 4.19° (vertical screen dimension), recorded data at 60 fps, and yielded an image of 482 × 640 pixels at full-screen resolution. A vertically directed thermal imaging camera and a fixed-beam vertical pointing Pathfinder radar, Model 3400 (Raytheon Inc., Manchester, NH) was used with a parabolic antenna (61-cm diam) that produced a beam width of 4° to monitor bird, bat, and insect movements based on the characteristics of tracks in the video images and the altitude of the target derived from the radar unit. Data from the thermal imaging camera and radar were combined into a single video image and stored on digital videotape. This approach produced quantitative data on migration traffic at several altitudinal bands and made it possible for the investigators to distinguish birds from insects and foraging bats.

Horn et al. (2008) deployed 3 FLIR Systems S-60, uncooled, microbolometer thermal infrared cameras (FLIR, North Billerica, MA), with matched and calibrated 25° lenses to observe the behavior of bats in the vicinity of operating wind turbines at the Mountaineer Wind Energy Center in the Mid-Atlantic Highlands, West Virginia (Fig. 3). Data were captured at a rate of 30 fps and recorded directly to external 250-gigabyte hard drives that were connected to laptop computers. Horn et al. (2008) showed that bat activity near wind turbines during August was highly variable on a nightly basis, with most of the activity of bats occurring during the first 2–3 hours after sunset (Fig. 4). Although airborne insects were most active in the first several hours after sunset, their activity was highly variable.

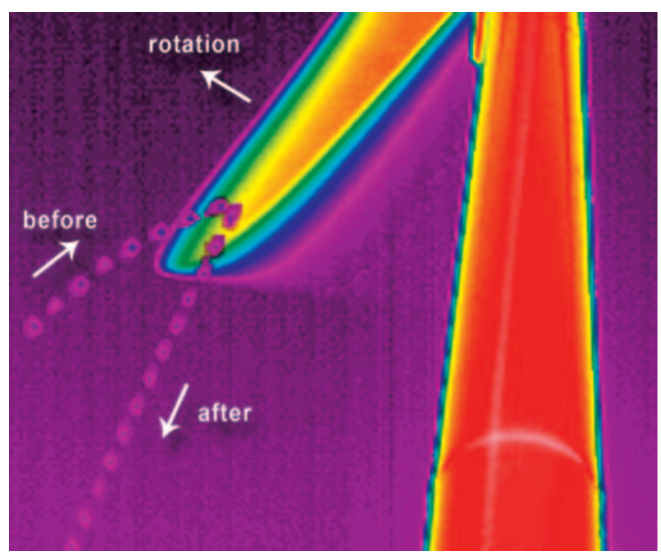


Figure 5. A time-lapse series of 21 sequential frames of thermal infrared video of a medium-height bat immediately before and after collision with an operational wind turbine recorded on 14 August 2004 at the Mountaineer Wind Energy Center, Tucker County, West Virginia, USA. The bat approached the moving blade on a curving trajectory before contact, but its heading and speed changed rapidly as the bat accelerated toward the ground. Only the single frame of video in which contact occurred is shown for clarity (from Horn et al. 2008).

Horn et al. (2008) suggested that the probability of being struck by moving turbine blades (Fig. 5) could be predicted by a combination of insect activity aloft and nightly weather conditions. In addition to bats struck directly by moving turbine blades, Horn et al. (2008) also observed flying bats investigating moving rotors and the monopole. Bats sometimes alighted upon and appeared to explore the monopole and rotor blades, suggesting that they may be attracted to these structures.

Results from thermal infrared imaging cameras ideally should be compared with other methods including radar and acoustic detection for monitoring bird and bat movements in the lower atmosphere at the height of wind turbines (Liechti et al. 1995, Gauthreaux and Livingston 2006). Many of the limitations of other visual methods are common to thermal infrared imaging, but the latter method also incurs a relatively high cost with large data-processing requirements. Current costs for the purchase of suitable thermal infrared cameras ($60,000–200,000) are expected to decrease in the near future.

*Light tagging.*—Small chemiluminescent light tags or mini glow sticks offer the potential for observing the flight behavior of individual bats in the vicinity of proposed and operational wind-energy facilities. Light tags have been used to mark bats for investigations of roosting and foraging behavior (Barclay and Bell 1988, Kunz and Weisse 2008). Small, chemiluminescent capsules (2 × 11 mm), manufactured as fishing lures, make excellent temporary light tags for marking and observing bats at night. Battery-powered light-emitting diodes (LEDs) also can be used for marking and observing bats flying at night (Barclay and Bell 1988, Kunz and Weisse 2008). Depending upon the size of the battery and the oscillation frequency of LEDs, such tags can last up to 14 days. Commercially produced LED tags are available in green and red light and are relatively small (3 × 12 mm and 1.0 g), with the battery and circuitry encapsulated in inert waterproof epoxy (Holohil Systems Ltd., Carp, ON, Canada).

Chemiluminescent tags and LEDs should be attached to the mid-dorsal region of bats with SkinBond™ surgical adhesive (Smith & Nephew, Largo, FL). Attaching light tags to the ventral surface of bats should be avoided, because a tag in this position may interfere with females if they have dependent young. Buchler (1976) and Buchler and Childs (1981) used chemiluminescent light tags to assess the dispersal, commuting, and foraging behavior of insectivorous bat species. Other investigators (e.g., LaVal and LaVal 1980, Aldridge and Rautenbach 1987) have used chemiluminescent and LED tags with the greatest success when observations were made in open areas, in flyways, and along forest edges and, thus, such tags may be particularly valuable for observing bats in the vicinity of wind turbines.

Use of chemiluminescent light tags may offer opportunities to observe the behavior of bats in response to sounds produced by moving wind-turbine blades or to insects that may attract bats to these structures (NRC 2007). Buchler and Childs (1981) attached light tags to big brown bats (*Eptesicus fuscus*) and found that individuals navigated to feeding grounds by following acoustic cues produced by calling frogs and stridulating insects. Light tags also can be used to follow individuals while their echolocation calls are monitored with ultrasonic detectors and, thus, can be used to validate species-specific calls (J. Swewczak, Humboldt State University, personal communication).

The primary limitation of chemiluminescent tags is that they remain illuminated only for a few hours. By contrast, LED tags can last upwards of 2 weeks. Another limitation is that bats often fly rapidly beyond the field of view, and generally cannot be followed in heavily forested areas. Moreover, in some instances light-tagged bats may be difficult to distinguish from flashing fireflies. More recent evidence suggests that bats carrying light tags may interfere with the social interactions of roosting bats (Kunz and Weisse 2008).

*Analysis of visual data.*—With the exception of data derived from light tags, visual-based surveys of bat activity using ceilometers, night vision, and thermal imaging cameras should report number of passes per recording hour or mean number of passes per recording hour. For consistency and comparison, recording time should be normalized to minutes past sunset. This protocol facilitates pooling and comparing data throughout a season or across multiple seasons (Horn et al. 2008). In addition to assessing overall activity, data should be documented by date, camera type, and lenses used to characterize temporal or spatial peaks in activity. Data on bat, bird, and insect activity derived from thermal infrared imaging or other visual methods should be compared with meteorological data to establish potential effects of these variables on relative abundance and nightly and seasonal activity.

**Radio Detection and Ranging (Radar)**

Radio detection and ranging (radar) has been used for over half a century to investigate nocturnal flight activity of birds, insects, and bats (Eastwood 1967, Vaughn 1985, Gauthreaux and Belser 2003, Larkin 2005, NRC 2007). However, only recently has this technology been used to evaluate the activity of airborne targets in the vicinity of wind-energy facilities (Mabee and Cooper 2004, Desholm et al. 2006, Gauthreaux and Livingston 2006, Mabee et al. 2006*a*, *b*). Radar operates by transmitting pulses of electromagnetic radiation (radio waves) and then receives the waves that reflect back from an object (e.g., insect, bird, bat, plane, or ship). Radio waves travel close to the speed of light and the distance to the object is, thus, related to the time lapse between transmission and reception of the echo. Detection of objects at a distance depends upon many factors, including area of the radar cross-section of the object, and the wavelength and power output of the radar. For birds, this distance may vary from a few hundred meters when using the smallest marine radars to >200 km in the case of long-range weather surveillance radars. For more details on theory and operation of radar, see Skolnik (1990) and Larkin (2005).

*Weather surveillance radar.*—Weather Surveillance Radar-1988 Doppler, also known as Next Generation Radar (NEXRAD) provides a network of weather stations in the United States operated by the National Weather Service (NWS), making it possible to monitor movements of insects, birds, and bats that move over large areas (i.e., within approx. 200 km). The United States military, local television stations, and municipal airports use similar weather radar systems, but data generated by these installations generally are not available to researchers. Data generated by the NWS-operated NEXRAD facilities can be downloaded free of charge via the Internet. Data generated from these weather surveillance radars can be used to determine general migratory patterns, migratory stopover habitats, roost sites, and nightly dispersal patterns (Fig. 6), and to assess the effects of weather conditions on these behaviors (Diehl et al. 2003, Gauthreaux and Belser 2003, Diehl and Larkin 2004, Horn 2007, NRC 2007).

However, NEXRAD cannot be used to characterize high-resolution passage rates or altitudinal data over small spatial scales (the min. resolution is $1^{\circ} \times 250$ m, which is about 0.2 km$^2$ at 40-km range). The high resolution of NEXRAD often makes it difficult to filter out insect noise from data on birds and bats because it does not provide information on individual targets. Owing to the curvature of the earth and resultant shadows (e.g., areas behind hills or other objects that shield targets from radar), NEXRAD radar cannot provide spatial coverage at or below wind turbine height. Notwithstanding, NEXRAD can be a valuable tool for assessing spatial and temporal patterns of daily and nightly dispersal of birds and bats (Russell and Gauthreaux 1998, Diehl et al. 2003, Kunz 2004, Horn 2007; Fig. 7).

*Tracking radar.*—Tracking radar systems, originally designed to lock onto and follow targets such as aircraft or missiles, can provide information on flight paths of individual insects, birds, and bats (including altitude, speed, and direction) including wing-beat signatures to discriminate these taxa while in flight (Fig. 8). Several applications using tracking radar have been described for birds (Able 1977, Kerlinger 1980, Larkin 1991, Bruderer 1994, Liechti et al. 1995), bats (Bruderer and Popa-Lisseanu 2005), and insects (Drake 1985, Drake and Farrow 1989, Wolf et al. 1995, Chapman et al. 2004, Geerts and Miao 2005). To date, tracking radar has not been commonly used to assess movements of birds and bats at wind-energy facilities because 1) this instrument does not provide a broad view of migration over a given site, 2) it is not widely available, and 3) it is difficult and expensive to maintain and repair.

*Marine radar.*—Marine (X-band) radar systems were originally designed for use on moving boats, but they also have been used as mobile units on land for research and monitoring of airborne targets, including passage rates, flight paths, flight directions, and flight altitudes of nocturnal migrating targets. Mobile marine radar laboratories often consist of units that are mounted on top of a vehicle, trailer, or on a ground-based platform (Fig. 9). When the antenna is in the horizontal position (i.e., in surveillance mode), the radar scans the surrounding area and can be used to collect information on flight direction, flight behavior, passage rates, and ground speeds of targets (Table 1). When the antenna (or a second antenna, if unit is equipped with 2 radars) is placed in the vertical position (i.e., in vertical mode), it can be used to measure flight altitudes (Table 1). Configurations of marine radar antenna also can be modified to measure flight altitudes with a parabolic dish (Cooper et al. 1991, Gauthreaux 1996) or by a horizontal antenna configured in a vertical position (Harmata et al. 1999).

Marine radars have been used at several proposed and operational wind-energy facilities in the United States. The principal advantage of these systems over Doppler and tracking radars is that they are relatively inexpensive, are available off-the-shelf, require little modification or maintenance, have repair personnel readily available worldwide, are dependable and easy to operate, are highly portable (can mount on vehicles, boats, or small platforms on land), have high resolution, and can be modified to collect altitudinal information by changing their broadcast to a vertical mode.

Largely because of these factors, most research and monitoring studies conducted on birds and bats have been accomplished using marine radar systems (Harmata et al. 1999, Cooper and Day 2004, Mabee and Cooper 2004, Desholm et al. 2006, Mabee et al. 2006*a*). However, like NEXRAD, marine radar generally is not capable of differentiating bird and bat targets. Although it has long been assumed that marine radar can be used to document the presence and flight activity of bird targets (Cooper and Day 2003, Mabee and Cooper 2004, Raphael et al. 2002, Day et al. 2005), researchers have recently acknowledged that images derived from marine radar targets also include bats (Gauthreaux and Livingston 2006, Larkin 2006).

Numerous preconstruction studies have used marine radar to estimate passage rates and altitudinal distributions of migrating targets (Mabee and Cooper 2004, Mabee et al. 2006*b*). Typically, a single radar unit is deployed at a central location on a wind-energy project area to maximize observable airspace for 30–45 days during spring (approx. 1 Apr through late May) and autumn (approx. early Aug through early Oct) migration periods. Rarely have portable radar units been deployed for a full annual cycle associated with wind-energy projects, and rarely have radar-sampling protocols been designed to address specific research hypotheses. Most monitoring studies of airborne targets near proposed or operational wind-energy facilities have deployed marine radar between civil sunset and 0230 hours, assuming this to be the peak period of nocturnal migration for birds on a given night (Gauthreaux 1972, Kerlinger 1995, Mabee et al. 2006*b*).

Objectivity and accuracy in identifying flying animals at night is a major challenge when using radar (Larkin 1991). Differentiating among various targets (e.g., birds, bats, and insects) is central to any biological radar study. However, because flight speeds of bats overlap with flight speeds of passerines (i.e., $>6$ m/sec; Larkin 1991; Bruderer and Boldt

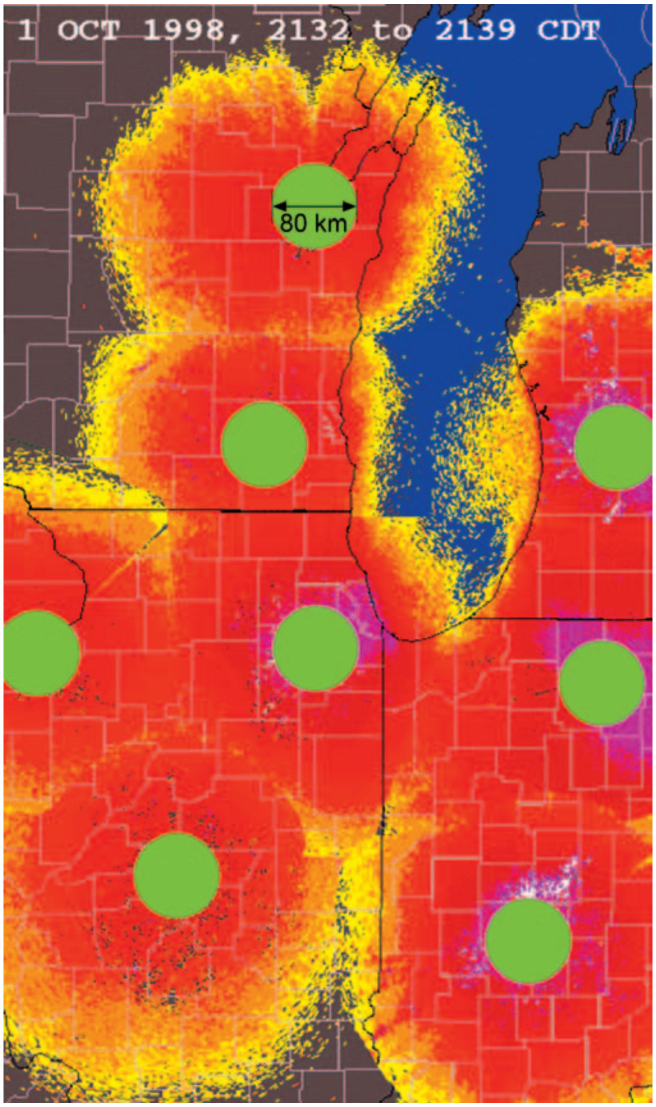


**Figure 6.** Composite of 8 Next Generation Radar (Weather Surveillance Radar-1988 Doppler) images taken at the lowest elevation angle (0.5°) on a typical night of widespread migratory activity in the mid-western USA, 1 October 1998. All pixels that are not background color (gray) are radar echoes from a mixture of flying birds, bats, and insects. Because of Earth's curvature, the radar beam is so high at a certain distance (range) that it no longer detects flying animals, thus producing a roughly circular echo around each radar installation. Green circles show the approximate maximum radar range at which flying animals can be detected at or below the height of the top of the rotor sweep of a modern wind turbine. Radar echoes outside those circles are higher than a wind turbine. Typical of such images from large radars, no flyways or migratory corridors are visible (R. H. Diehl, University of Southern Mississippi, unpublished data).

2001; B. A. Cooper and R. H. Day, Alaska Biological Research [ABR, Inc.]), unpublished data), generally it is not possible to separate bird targets from bat targets based solely on flight speeds. Foraging bats sometimes can be separated based on their erratic flight patterns. However, migratory bat species and those that do not engage in erratic flight behavior while foraging may be indistinguishable from migratory songbirds on radar. Visual verification of a sample of radar targets can be accomplished using night-vision devices or thermal imaging cameras and information on the proportion of birds versus bats from a site within the zone of

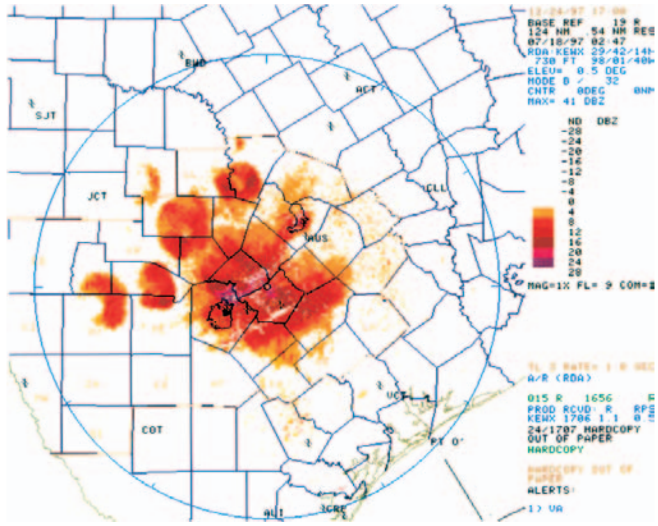


**Figure 7.** Next Generation Radar (Weather Surveillance Radar-1988 Doppler) images of Brazilian free-tailed bats (*Tadarida brasiliensis*) dispersing nightly from selected cave and bridge roosts in south-central Texas, USA, 18 July 1997. Similar images can be observed when colonial birds disperse from roosting sites early in the morning. Such images make it possible to identify major roosts but also show directions and relative densities of dispersing bats or birds. Data were recorded at an elevation angle of 0.5° (from Kunz 2004).

radar coverage can be related to the radar targets (Gauthreaux 1996; Gauthreaux and Livingston 2006; B. A. Cooper and T. Mabee, ABR, Inc., unpublished data). Use of double-sampling or other quantitative methods for estimating detection probabilities (e.g., Program DISTANCE [Anderson et al. 1999]) should be used in such studies to characterize detection biases.

Because insects also are detected with marine radar, it may be necessary to reduce or eliminate the radar signals from insects if both birds and bats are the targets of interest. Reflectivity from insects in radar surveillance can be reduced by filtering out all small targets (grain size) that only appear within approximately 500 m of the radar and targets with poor reflectivity (i.e., targets that move erratically or inconsistently at locations with good radar coverage) and by editing data prior to analysis by omitting flying animals with corrected airspeeds $<6$ m per second (Diehl et al. 2003). Application of a 6-m/second–airspeed threshold is based on radar studies that have determined most insects have airspeeds of $<6$ m per second, whereas flight speeds of birds and bats usually are $\geq 6$ m per second (Larkin 1991; Bruderer and Boldt 2001; B. A. Cooper and R. H. Day, unpublished data).

Energy reflected from the ground, surrounding vegetation, and other solid objects that surround the radar unit typically creates ground-clutter echoes that appear on display screens. Ground clutter can obscure targets, although it can be minimized by elevating the forward edge of the antenna and by siting the radar unit in locations that are surrounded closely by low vegetation, hills, and anthropogenic structures. These objects act as radar barriers by shielding the radar from low-lying objects further away from the radar, while producing only a small amount of ground clutter in

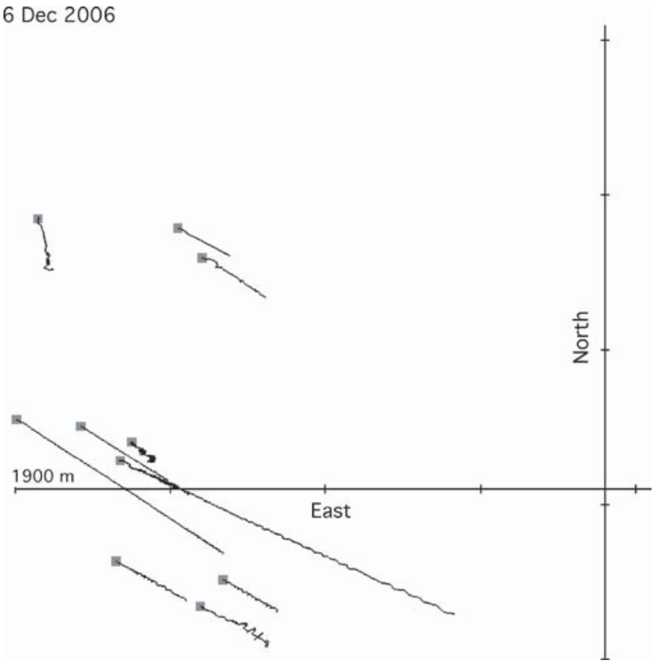


**Figure 8.** A composite of 10 paths of flocks of waterfowl in late autumn recorded with an instrumentation tracking radar (WF-100) at the Illinois Natural History Survey, USA, recorded 6 December 2006. North is at the top and tic marks are at 1-km intervals. The start of each path is marked with a square. The average error (SE of a linear fit) is <0.4 m for the straight paths; irregularities are largely due to flocks that were partly obstructed by intervening buildings. The northwestern-most track, which is nonlinear, is a flock descending through a dry, micro-weather front. Echo size and modulations (not shown), verification from Doppler radar KILX (Lincoln, Illinois), and time of day and year helped establish the identity of these targets (R. P. Larkin, Illinois Natural History Survey, unpublished data).

**Figure 9.** Mobile marine (X-band) laboratory equipped with capacity for vertical and horizontal antenna positions (B. A. Cooper, Alaska Biological Research, Inc., unpublished data). Depending upon specific applications, the antenna can be aligned in a horizontal (for assessing direction and passage rate) and vertical mode (for assessing altitude).

the center of the display screen (Eastwood 1967, Williams et al. 1972, Skolnik 1990, Cooper et al. 1991, Larkin 2005).

Simultaneous deployment of marine radar with other methods (e.g., night-vision devices, thermal infrared imaging, and acoustic detectors) should improve our knowledge of nocturnal species activity and our ability to estimate exposure (i.e., use and risk) at proposed sites, and is likely to improve our ability to distinguish birds from bats during monitoring efforts. Species composition and size of biological targets observed with marine radar is usually unknown. Thus, the term target, rather than flock or individual, is currently used to describe animals detected with marine radar. Occasionally, there are situations where a particular species has unique flight patterns that make it possible to identify species-specific targets. For example, marbled murrelets (*Brachyramphus marmoratus*) can be identified on radar with a high degree of accuracy at inland nesting locations (Hamer et al. 1995; Burger 1997, 2001; Cooper et al. 2001, 2006), and Hawaiian petrels (*Pterodroma sandwichensis*) and Newell's shearwaters (*Puffinus auricularis newelli*) were identified as they dispersed to and from colonies in Hawaii (Day and Cooper 1995, Cooper and Day 2003, Day et al. 2003). However, such results should be verified with simultaneous acoustic and visual observations. For studies using marine radar, independent confirmation of

**Table 1.** Comparison of flight directions, overall passage rates, and flight altitudes of radar targets at central and other sites near Mt. Storm, West Virginia, USA, during autumn 2003 ($n$ = no. of nights surveyed).

| | | | Comparison site | | Central site | | Test statistics[b] | | |
|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Site** | $n$ | $\bar{x}$ | **Dispersion**[a] | $\bar{x}$ | **Dispersion**[a] | $Z$ | $W$ | $P$ |
| Flight direction (degrees) | Northern | 18 | 197° | 0.58 | 177° | 0.56 | | 1.40 | 0.496 |
| | Southern | 22 | 191° | 0.53 | 207° | 0.42 | | 1.06 | 0.588 |
| | Eastern | 19 | 193° | 0.91 | 178° | 0.31 | | 19.25 | <–0.001 |
| | Western | 17 | 219° | 0.70 | 191° | 0.36 | | 3.23 | 0.199 |
| Passage rate (targets/km/hr) | Northern | 17 | 225 | 57 | 292 | 66 | –1.49 | | 0.136 |
| | Southern | 21 | 168 | 31 | 239 | 37 | –1.96 | | 0.050 |
| | Eastern | 21 | 54 | 10 | 220 | 52 | –3.77 | | <–0.001 |
| | Western | 20 | 127 | 22 | 230 | 47 | –2.70 | | 0.007 |
| Flight altitude (m above ground level) | Northern | 16 | 448 | 29 | 439 | 37 | –0.52 | | 0.605 |
| | Southern | 21 | 447 | 31 | 467 | 33 | –0.57 | | 0.566 |
| | Eastern | 16 | 509 | 23 | 427 | 41 | –2.02 | | 0.044 |
| | Western | 17 | 436 | 20 | 472 | 30 | –0.97 | | 0.332 |

[a] $\bar{x}$ vector length ($r$) for directional data; SE of the $\bar{x}$ for passage rates and flight altitudes.
[b] Test statistics are for Wilcoxon paired-sample test ($Z$) and Mardia–Watson–Wheeler (Uniform Scores) test ($W$).

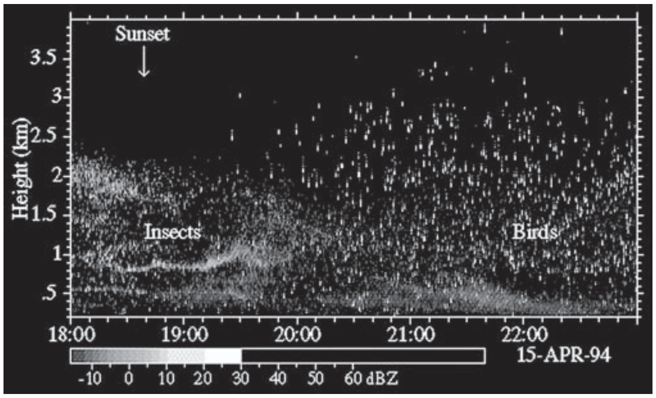


**Figure 10.** Vertical distribution of airborne fauna, recorded using vertically pointing profiler radar on 15 April 1994. Note that targets identified as insects drop markedly in altitude in the period before sunset until 2400 hours. Most of the larger targets (assumed to be migrating birds and bats) are active at a wide range of altitudes (McGill University, Montreal, Canada 2000).

species identity is needed if species-specific information is being reported.

A concern common to all marine radar studies is that there are locations where even a skilled and experienced radar operator cannot find a suitable sampling site because the zone of primary interest (i.e., at or below turbine ht) is obscured by shadow zones of radar or areas of ground clutter. One of the most important and difficult-to-learn aspects of using marine radar is the selection of sampling locations. The site chosen has important implications for data quality and comparability among sites. Sites must be chosen where ground clutter and shadow zones do not obscure or omit important portions of the study area. One additional technique that allows greater flexibility in siting is to mount the radar on a lift that can be elevated to a desired height above surrounding vegetation (Cooper and Blaha 2002). This technique is particularly useful in relatively flat, heavily wooded areas. To ensure reliable data acquisition, all radar devices must be calibrated before being deployed in the field and users must be fully trained in field-sampling techniques to ensure reliable data collection.

*Case study I: nocturnal migration at the Mount Storm wind project.*—Mabee et al. (2006*b*) used a portable marine radar system in 2003 to collect information on the migration characteristics of nocturnal birds (particularly passerines) during the autumn migration period in the vicinity of the Mt. Storm Wind Power Project in West Virginia. The objectives were to 1) collect and compare information on flight directions, migration passage rates, and flight altitudes of nocturnal migrants at multiple sites near or within this proposed development; 2) determine if nocturnal bird migration occurred in a broad front; and 3) determine if nocturnal migrants follow the Allegheny Front ridgeline within the proposed project area.

The study design involved using one marine radar at a central site (sampling approx. 6 hr/night) and a second radar unit that could be moved between 4 secondary sites (i.e., northern, southern, eastern, or western locations) and sampled approximately 2.5–3 hours per site per night. All paired comparisons were made with concurrent data from the central site. Observer assignments and starting locations of the second mobile radar laboratory were varied systematically to minimize bias among sites and observers. Flight directions and altitudes at sites along or near the ridgeline were not different from each other, but significant differences in passage rates were observed among some of these sampling sites (Table 1). These data demonstrated that nocturnal migrants crossed rather than followed the Allegheny Front ridgeline (Mabee et al. 2006*b*).

*Case study II: nocturnal bird migration at the Stateline wind project.*—Situated on privately owned dryland agricultural and grazing land, the Stateline wind-energy facility consisted of 454 Vestas V-47 wind turbine (Danish Wind Technology, Ringkøbing, Denmark) rated at 660 kW each, with 273 turbines located in Walla Walla County, Washington, USA, and 181 turbines located in Umatilla County, Oregon, USA. Several studies were conducted by Mabee and Cooper (2004) to meet the permit requirements in Oregon (state permitting process) and in Washington (county permitting process). After the original permits were granted, the developer (Florida Power and Light Energy [FPLE]) sought an amendment of its county permit in Washington to build strings farther to the north and closer to the Columbia River. Based on negotiations with the Blue Mountain Audubon Society, a condition of permit approval was granted that required FPLE to support these nocturnal studies. The results of this research were evaluated by a technical advisory committee to determine whether the risk associated with siting turbines in this area was tolerable.

The specific hypotheses tested were that the mean flight altitudes and mean target rates were the same near the area where the new turbines were proposed compared to the altitudes and passage rates observed at a control area to the south, away from the Columbia River. To test this hypothesis, 2 marine radar units were used concurrently during 2 autumn and one spring period for 6 hours per night per radar (Mabee and Cooper 2004). Mean passage rates and flight altitudes were compared between the 2 locations using the nonparametric Wilcoxon signed-rank test (Tables 2, 3). No significant differences between mean passage rates and flight altitudes were determined between the 2 locations (Tables 2, 3).

*Emerging radar technologies and applications.*—The National Aeronautics and Space Administration recently developed high-resolution polarimetric weather radar (NPOL) that promises to be more useful for studying movements of birds and bats than NEXRAD. Because of its high resolution, NPOL can be used to collect data on individual targets and potentially discriminate between insects, birds, and bats. More recent developments of Collaborative Adaptive Sensing of the Atmosphere (University of Massachusetts, Amherst, MA) have designed a series of Distributed Collaborative Adaptive Sensing networks that will sample the atmosphere at altitudes below those typically detected with NEXRAD. Use of data

**Table 2.** Mean nocturnal rates of movement (targets/hr ± 1 SE) of all targets observed during short-range radar sampling (1.5 km) at Hatch Grade, Washington, USA, and Vansycle Ridge sites, Oregon, USA, during autumn 2000, spring 2001, and autumn 2001. ($n$ = no. of concurrent sampling nights).

| | | Movement rate | | | Wilcoxon signed-ranks test | | |
|---|---|---|---|---|---|---|---|
| **Season** | **Location** | $\bar{x}$ | **SE** | $N$ | $Z$ | $N$ | $P$ |
| Autumn 2000 | Hatch Grade | 58.1 | 6.3 | 23 | | | |
| | Vansycle Ridge | 53.1 | 5.7 | 23 | −0.08 | 23 | 0.94 |
| Spring 2001 | Hatch Grade | 135.3 | 19.9 | 43 | | | |
| | Vansycle Ridge | 144.8 | 18.6 | 43 | −1.2 | 43 | 0.23 |
| Autumn 2001 | Hatch Grade | 64.8 | 7.6 | 23 | | | |
| | Vansycle Ridge | 78.8 | 7.5 | 23 | −2.18 | 23 | 0.03 |

generated using Multiple Antenna Profiler Radar (MAPR) also holds considerable promise for characterizing temporal and elevational profiles of insects, birds, and bats during clear air periods. A MAPR is an advanced radar system being developed at the National Center for Atmospheric Research and Earth Observing Laboratory to make rapid wind measurements of targets within the Earth's boundary layer (Fig. 10). These and other recent radar developments (NRC 2002, Larkin 2005) promise to advance future research on the behavior and activity of airborne organisms, including those in the vicinity of wind-energy facilities (A. Kelly, DeTect, Inc., personal communication).

### Acoustic Monitoring of Birds

Ornithologists have long used acoustic monitoring of nocturnal migrants to better understand bird migration (Libby 1899, Ball 1952, Graber and Cochran 1959, Balcomb 1977, Thake 1981). With the publication of type-specimen (archived) flight calls annotated by experts (Evans and O'Brien 2002), the practice of listening to flight calls of birds at night has broadened from being an academic to a practical method of monitoring bird migration (reviewed in Farnsworth 2005).

Because nocturnal calls of passerines (songbirds) are heard most frequently, research has centered on this group (Palmgren 1949, Svazas 1990, Farnsworth 2005). However, birds such as upland sandpiper (*Bartramia longicauda*) and woodcock (*Scolopax minor*) also produce calls at night.

*Equipment requirements.*—Any outdoor acoustic study poses challenges for sensors and cables, including moisture, vandalism, lightning, and physical abuse. Exclusive of supports such as masts, towers, and kites required to elevate, stabilize, and shelter a multi-microphone array, equipment for an acoustic study of birds involves the following:

More than one microphone is necessary to obtain information on location and flight altitude. An ideal microphone offers good sensitivity (current generated by slight changes in pressure), low internal noise level (e.g., low hum, shot noise, and crackle inside the electronic equipment), resistance to extremes of moisture and temperature, and affordable cost. Sensitivity usually is desired more in one direction than others. A good directional microphone (which varies by cost and portability) will greatly amplify sounds arriving on its axis and be less sensitive to sounds from other directions. Any microphone used for bird flight calls should be sensitive to sounds ranging from about 10 kilohertz (kHz) to 1.5 kHz, preferably lower. Preamplifiers are placed close to microphones to amplify weak electrical signals from the microphone to a level that can be transmitted to a recording device without distortion. Preamplifiers require power to operate, and most will function for an entire night or longer on a set of small batteries.

Unless all equipment is bundled, good weatherproof cables are necessary, not optional, for outdoor work. A complete set of replacement cables will eventually save a night's worth

**Table 3.** A comparison of mean nocturnal flight altitudes (m above ground level ± 1 SE) of targets observed during vertical radar sampling (1.5-km range) at Hatch Grade, Washington, USA, and Vansycle Ridge, Oregon, USA, during spring and autumn, 2001. Mean altitudes are calculated from total number of targets ($n_{total}$), whereas tests are based on the number of sampling nights ($n_{nights}$). Test statistics are Mann–Whitney ($U$) and Wilcoxon signed-rank ($Z$) values.

| | | Flight altitudes | | | Test results | | | |
|---|---|---|---|---|---|---|---|---|
| **Season** | **Location** | $\bar{x}$ | **SE** | $n_{total}$ | $U$ | $Z$ | $n_{nights}$ | $P$ |
| Intraseasonal[a] | | | | | | | | |
| Spring 2001 | Hatch Grade | 505.6 | 4.7 | 6,296 | | | | |
| | Vansycle Ridge | 578.5 | 4.8 | 6,521 | 181.0 | | 40 | 0.64 |
| Autumn 2001 | Hatch Grade | 647.4 | 7.0 | 2,172 | | | | |
| | Vansycle Ridge | 605.6 | 7.5 | 2,553 | | −1.60 | 14 | 0.11 |
| Interseasonal | | | | | | | | |
| Spring 2001 | Hatch Grade | 454.8 | 33.9 | | | | | |
| Autumn 2001 | Hatch Grade | 649.4 | 21.9 | | 45.0 | | 36 | <0.01 |
| Spring 2001 | Vansycle Ridge | 481.1 | 36.3 | | | | | |
| Autumn 2001 | Vansycle Ridge | 610.8 | 27.9 | | 69.0 | | 32 | 0.03 |

[a] One FR-1510 vertical radar alternated between sites (spring 2001), whereas 2 radars sampled concurrently during autumn 2001.

of data. Alternatively, an elevated acoustic sensor (microphone + preamplifier) might be used to transmit a radio signal to a nearby receiving station on the ground. Digital devices such as high-density computer disks are an attractive substitute for the formerly used audiotape or video home system (VHS) videotape. Changing batteries and starting and stopping recording devices can involve substantial personnel costs if many units are deployed. Postconstruction studies may have line power available from wind turbines.

In field applications, the most serious problem will often be the masking of flight calls by ambient noise, including wind noise, insects, wave noise, and turbine nacelle and rotor noise (for postconstruction studies). Because researchers prefer to block spurious reflections into the microphone, the interior of any sound barrier should be made of a nonreflective surface. (Hay bales and closed-cell foam are excellent for absorbing extraneous sounds.) Because most flight calls of interest are produced at moderately high frequencies (>1.5 kHz), sound barriers should be nearly airtight to prevent sound from passing through small openings. Widescreen, open-cell foam is often used to reduce wind noise when sound transducers are exposed to wind.

*Acoustic identification of calling songbirds.*—Early studies regarded species identification of flight calls at night to be more art than science. More recently, intensive fieldwork has enabled researchers to identify many individual species and a few broader groups of similar-sounding species, but confidence in identification largely depends on the skill of the individuals conducting the studies. Whereas some nocturnal flight calls of birds are easy to identify because they are identical to well-known and distinctive ones heard during the day, discriminating groups of species with flight calls that are similar-sounding to the ear and similar-looking on sonograms is a major challenge that calls for more sophisticated analyses of flight calls beyond detailed changes in acoustic frequency and bandwidth over time. For example, song recognition in some *Catharus* thrushes appears to be accomplished largely by sensing the sound frequency (pitch) ratio of different notes to each other (Weary et al. 1991).

For most field studies relying on acoustic monitoring of bird calls, an important cost question is whether an expert listener will spend hundreds of hours listening to and classifying recordings or if sophisticated voice-recognition software will be used to speed or perhaps assume that task (Larkin et al. 2002). If project design requires a comprehensive analysis of nocturnal flight calls, only partial automation is technologically realistic at the present time. Recent developments in recognition of animal vocalizations, particularly bird song and cetacean sounds, may in the future be adapted for classification of bird calls made in flight (NRC 2007). However, computer methods used to sort flight calls also rely on expert-system algorithms and the experts who develop and refine them. Flight calls that are readily identifiable with confidence include some species of conservation concern (Russell et al. 1991), especially species whose populations are declining.

*Enumerating nocturnal songbirds.*—Quantification of flight calls of migrating songbirds from acoustic recordings has suffered partly because, even when one can enumerate the calls from various identified species, the volume of air being sampled is difficult to estimate for calls of poorly known intensity (i.e., loudness). However, if researchers concerned with wind power and wildlife issues and using a good acoustic recording system know that flight calls are within the rotor-swept zone, they can state that those calls are at most about 125 m above the ground for a modern, onshore, utility-scale wind turbine. At such distances, neither spreading loss nor atmospheric absorption should be important. Assuming that ambient noise is acceptable, such distances should provide good signal-to-noise ratios, and careful measurement of the directionality of the microphones should permit calculation of the sampling volume. If the passage rate of birds over or among the microphones and within the useful range of heights can also be measured (e.g., using marine radar), and calls per rotor area per time can be estimated.

The numbers of calls vary over the course of a night. Variables include temporal variation from the ground (as birds gain or lose ht), numbers of migrants of different species above a microphone at different times, time-varying shadows of large bodies of water from which no land birds took flight at sunset (W. R. Evans, OldBird, Inc., personal communication), and temporal variation in the rate of calling of individual birds. Like other methods of monitoring nocturnal migrant birds, there is also high variability in the number of calls heard among nights, so that sampling must be conducted over an extended period to achieve confidence in the results (Evans 2000, Howe et al. 2002). Not all migrating passerines produce calls at night, and those that do may not call when they pass over a microphone.

To reliably estimate bird abundance or, more ambitiously, species numbers flying past wind turbines or potential wind turbines, one must count birds, not just flight calls (Lowery and Newman 1955). How often do birds of each species call? What is the relationship between the number of animals and the number of calls (when some animals are silent) and calls per animal (when animals vocalize more than once in the microphone range)? Little is known about the calling rate of migrating birds at night, and no biological theory exists even to formulate an hypothesis. Some observers report binaural tracking of a series of same-sounding notes in the dark, as if a single migrant were calling at intervals passing overhead, indicating that multiple calls from one bird do occur. By contrast, radar data show many more targets aloft than one hears from the ground; thus, most birds (including whole groups of species; reviewed in Farnsworth 2005) apparently do not regularly produce flight calls.

This conundrum is ameliorated by recent radar work showing that, in some instances, numbers of radar targets are

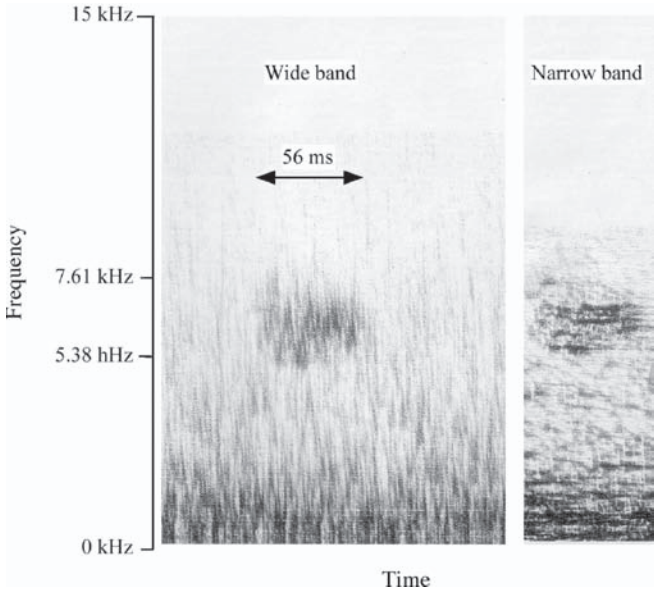


**Figure 11.** Sound spectrogram (sonogram) of flight call (unknown species) recorded on 22 September 1974 at Millbrook, New York, USA (R. P. Larkin, Illinois Natural History Survey, unpublished data).

correlated empirically with numbers of recorded flight calls (Evans 2000, Larkin et al. 2002, Farnsworth et al. 2004), indicating that flight calls may provide an index of migratory activity, at least in some circumstances. However, the basis for such correlations are yet to be discovered (Larkin et al. 2002), and currently there is no way to know if the finding can be applied generally or only in some situations.

*Flight altitude.*—Birds at night typically are not vulnerable to wind turbines unless they are in the height range of the rotor-swept zone, or when they are descending to ground level or taking off from the ground. Migrating birds in cruising flight often fly higher than the height of existing wind turbine rotors, and nocturnal aerial displays of birds often do not reach rotor height, with possible exceptions during inclement weather, take-offs, and landings. Bats may fly upward or downward toward wind turbines, but migrating birds do not seem to be attracted to them. However, assignment of flight altitude (agl) is challenging at best. It is not possible to localize a sound using a single microphone. A single-directional microphone is even poorer because the source of a sound that registers faintly may be on the axis of high sensitivity at a great distance or off the axis but still nearby.

More than one microphone and an accurate multi-channel recording or registering device can help detect the calls of flying birds (Evans 2000). If the signal to noise ratio is adequate, the difference in arrival latency of a flight call at different microphones separated in space can help locate the bird making the call. For locating a sound in $N$ dimensions, one needs high-quality sounds on $N$–1 microphones. Although marking a distinctive feature of a single call on multiple sonograms and measuring between the marks is often accurate enough, cross-correlation among several identical microphones generally produces better latency measures and better estimates of height, especially when a call contains no distinctive features.

A variant of this technique was used to estimate, or in rare cases measure, altitudes of birds flying over a prospective wind-energy facility in Nebraska, USA (Howe et al. 2002). Investigators used differences in sound arrival-times at 2 microphones vertically aligned at different altitudes on an open-framework tower, permitting conclusions about the altitudes of the calling birds.

Creative and complex variations on the multi-microphone approach include measuring the Doppler effect at each microphone, suspending additional microphones on aerial platforms (e.g., kite balloons), and using several calibrated directional microphones. For example, consider 2 directional microphones both positioned within the rotor-swept zone, spaced one above the other and aimed horizontally in the same direction. Any loud flight call arriving approximately simultaneously at the 2 microphones (depending on their spatial separation) should be from a bird at rotor height, either relatively close to the microphone or in the direction in which they are aimed.

Researchers using single microphones often report an estimated maximum effective range of the microphone for sounds such as bird calls, but fail to distinguish among birds flying above, within, or below rotor height. In this case, the acoustic recordings are of little value except to provide a partial species list of which kinds of birds are overhead, which kinds vocalize on a given night, and to what degree they vocalize. Moreover, flight calls of different species contain sound frequencies that attenuate at very different rates in the atmosphere and, thus, are audible at different maximum distances (see below) and rates of calling are sometimes related to cloud cover and perhaps cloud ceiling.

It is nearly impossible to interpret data gathered using acoustic recordings alone, in part because the biological context of the calls is open to question. Vocalizations are usually presumed to have a social function (Marler 2004), but nocturnal passerines in North America are not thought to fly in flocks the way birds fly in the daytime (Gauthreaux 1972, Larkin 1982, but see Moore 1990), and communication with birds on the ground is not out of the question. A plausible hypothesis has even been made for a height-finding function of flight calls by echolocation of the ground (Lowery and Newman 1955, Griffin and Buchler 1978). (This hypothesis should predict frequent calling when birds pass flow over a ridgeline.) Finally, it is not known whether sounds made by operating wind turbines interfere with recording the calls made by nocturnally migrating birds.

*Case example: recorded call quality.*—A sound spectrogram (sonogram) from a flight call was recorded on 22 September 1974 using a 2.5-cm sound-calibrated condenser microphone and Nagra analog tape deck (Fig. 11). Ambient noise lies mostly below 2 kHz and the call is in the mid-range of frequencies of calls of migrant birds. The fuzzy appearance indicates a marginal signal-to-noise ratio. Rather than a clear textbook example of a known species, this sonogram is representative of many ambiguous flight calls even when recorded on modern, high-quality equipment. This call lacks distinctive features useful for measuring time of arrival at the microphone or for determining the species of bird with any degree of certainty. A thorough discussion of call quality is treated by Evans (1994).

*Case study: pre- and postconstruction monitoring.*—Preconstruction studies at wind turbine facilities (Evans 2000, Howe et al. 2002) and postconstruction studies in Nebraska and New York (Evans 2000) have employed multiple microphones to estimate the altitude of passing migrants. Birds flying around tall communication towers on overcast nights are often reported to show a high rate of calling (Avery et al. 1976). Thus, postconstruction studies of calling birds must allow for the possibility that wind turbines attract calling birds, in which case calls may indicate increased vulnerability to collision with the tower structure or blades rather than a record of passing birds. Direct observation of bird flight paths, for example, from detailed tracking radar data, can verify or rule out this possibility.

**Acoustic Monitoring of Echolocating Bats**

All North American bats emit regular pulses of vocalizations during flight that create echoes used for navigation and for detecting and pursuing prey. Biological sonar, or echolocation, provides important acoustic information that can be detected and used to indicate the presence of bats, and in many cases to identify species. Except for a few species of bats that emit audible (to humans) echolocation calls, most bats vocalize at ultrasonic frequencies (well above the range of human hearing, >20 kHz). Various devices are available for detecting and converting ultrasonic calls of bats into audible sounds or data that can be captured on a tape recorder or a computer hard drive. However, the rapid aerial attenuation of high-frequency calls (Griffin 1971) can bias detection rates toward species that produce low-frequency sound. Bats can also generate sound intensities as high as 133 dB, among the loudest source levels recorded for any animal (Holderied et al. 2005). This renders many species detectable at ranges ≤30 m.

*High-intensity call bias.*—Because different bat species vary in their loudness (i.e., intensity), those that vocalize at low intensities will be less detectable and, thus, introduce a bias toward those species that produce high-intensity echolocation calls (Griffin 1958, Faure et al. 1993, Fullard and Dawson 1997). Low-intensity echolocators (e.g., *Corynorhinus* spp.), or so-called whispering bats, have a smaller effective volume of detection and, thus, may be missed during acoustic surveys unless they fly close to an ultrasonic detector (within 3–5 m for some species). However, this limited detection range also provides an advantage of increased spatial resolution (e.g., distinguishing between bats at ground level vs. those at rotor ht for acoustic monitoring programs with detectors placed at these different ht above the ground; Arnett et al. 2006, Reynolds 2006).

*Bat passes.*—Acoustic detection of bats provides a practical and effective means to monitor for bat presence, activity, and relative abundance (Fig. 12). We emphasize relative abundance, because, as with monitoring bird calls, current acoustic monitoring technology cannot determine the number of individual bats detected; it can only record events of detection, termed bat passes, of bats that enter the volume of airspace within detection range. A bat pass is defined as a sequence of >2 echolocation calls, with each sequence, or pass, separated by >1 second (Fenton 1970, Thomas and West 1989, Hayes 1997). Bat passes are commonly used as an index of activity or abundance, but it is important to understand that they do not indicate the number of individuals. One hundred different bats of the same species passing near an ultrasonic detector are generally indistinguishable from a single bat that returns to pass a detector 100 times. Thus, the data from monitoring echolocation calls of bats can only provide population indices or statistical proxies of relative activity or abundance (Hayes 2000).

Quantifying bat passes as an index of abundance can provide guidance as an index of bat occurrence, and with an appropriate study design these data can be resolved spatially and temporally (Parsons and Swezaczk 2008). Recorded levels of activity at any one site are not necessarily proportional to abundance because 1) of differential detectability of bat species, 2) all bat species may not call at the same rate (e.g., *Myotis* vs. *Lasiurus*), 3) all individuals within a given species may not call at the same rates (e.g., migrating vs. feeding), 4) some species may remain out of detection range of a detector despite their presence, 5) variable foraging behavior of some species (e.g., a detector deployed in the open is likely to miss bats that forage along the edge of vegetation), 6) weather and environmental factors, and 7) temporal variations in activity. The latter factor can vary on a scale of days as bats follow local insect activity or while in residence or during migration.

Bats exhibit dynamic movements across the landscape where they typically forage in several different locations each night (Lacki et al. 2007). Nightly activity as measured by bat passes can vary significantly at any one location so that a single night of data will not statistically represent the overall trend of bat activity at that location (Hayes 1997, Gannon et al. 2003). Beyond assessing the presence of a bat, confident identification to species requires even longer survey efforts, typically on the order of weeks (Moreno and Halffter 2001). Longer term temporal variations due to seasonal movements of bats, such as migration, are of vital concern because of the documented relationship between bat fatalities at wind-energy facilities during presumed migration (Johnson et al. 2004, Arnett et al. 2008). For each of these considerations, the best strategy for assessing potential interactions between bats and wind turbines is to implement a long-term acoustic monitoring program, best conducted throughout an entire annual cycle (Apr through Nov in temperate North America) to account for all potential variables and ideally covering ≥3 years to assess both within-year and inter-annual variability.

Acoustic monitoring generally cannot provide information on age, sex, or reproductive condition of bats, although recent evidence suggests that this may be possible for some

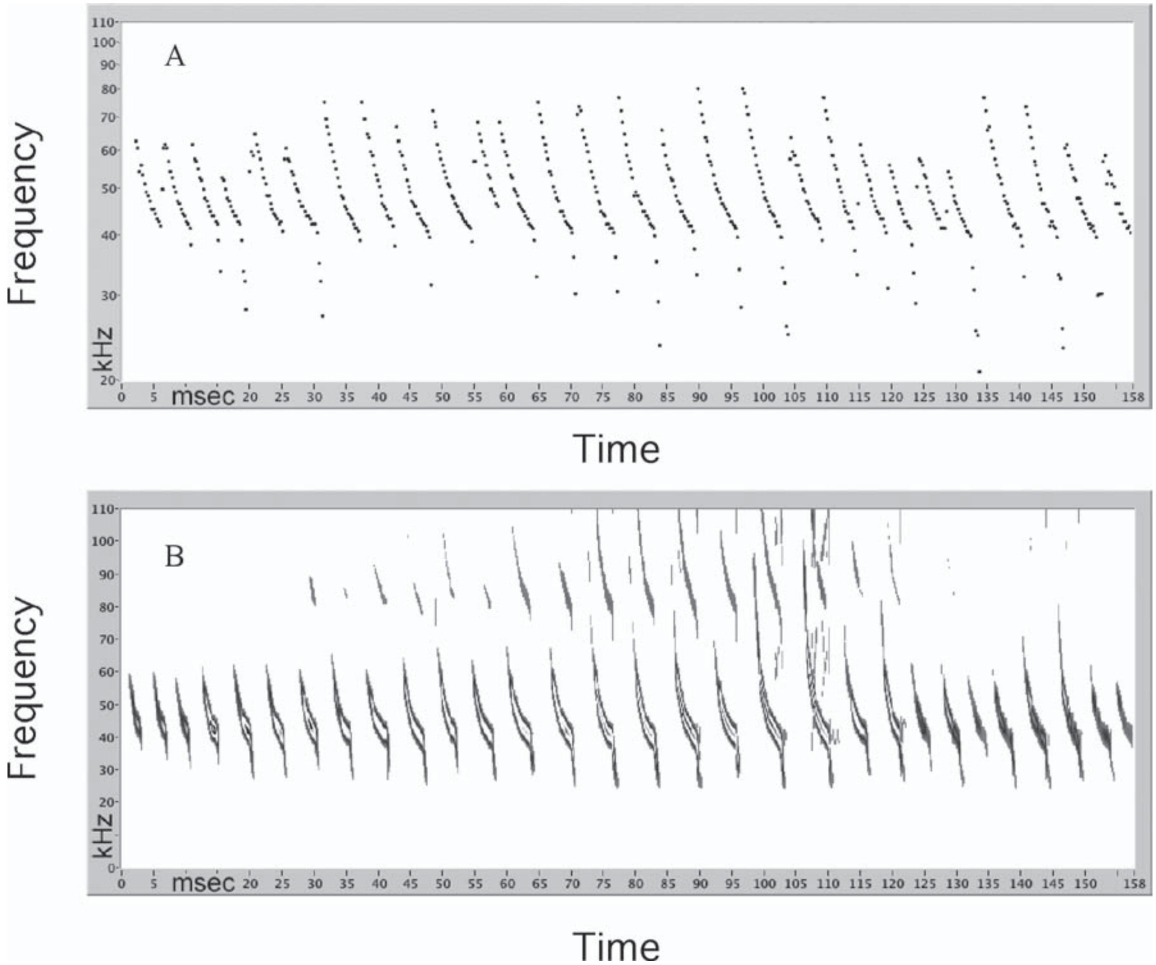


**Figure 12.** Sonograms of a small-footed myotis (*Myotis ciliolabrum*) flying past a recording bat detector recorded at (Birchim Canyon, near Bishop, CA, USA, 11 Jun 2001). Both panels display the same bat pass rendered with zero-crossing data reduction in the manner of an Anabat bat detector and Analook software (Titley Electronics, Ballina, New South Wales, Australia; A), and in full-spectrum data revealing amplitude distribution using a Pettersson detector (Pettersson Electronik AB, Uppsula, Sweden) and SonoBat software (SonoBat, Arcada, CA; B). In each sonogram the actual time between calls has been compressed to better display the calls. The zero-crossing processed sonogram is plotted with the frequency scale mapped logarithmically as is the convention with Analook, the Anabat processing software (J. Szewczak, Humboldt State University, unpublished data).

species (Siemers et al. 2005). For most species, however, obtaining such data requires that bats be captured, although captures are difficult or impractical to achieve in open environments at the heights of rotor-swept areas. Acoustic, visual, and radar observation methods provide an alternative to capture methods because the former do not interfere with the normal behavior and flight trajectories of bats. In addition, compared with visual methods and radar, acoustic monitoring methods better support long-term monitoring because of their lower data burden and ability to proceed remotely without the need for operating personnel (Reynolds 2006). However, questions remain as to whether migrating bats echolocate continuously while they are flying (Van Gelder 1956, Griffin 1970, Johnson et al. 2005). Thus, methods such as thermal infrared imaging or other night-vision methods should be used simultaneously with acoustic monitoring during expected times of migration until this issue can be resolved.

Acoustic detection and monitoring of bats begins with acquisition of a signal using a microphone sensitive to ultrasonic frequencies. A microphone and detector–recorder system having a frequency response up to 150 kHz suitably covers all North American bat species. The acquired ultrasonic signals must then be translated into a useable form. This can be accomplished by transforming ultrasonic signals into humanly audible tones for manual monitoring, or by directly converting the digital data for storage and processing. Digital data can then be transduced and interpreted by one of 3 primary approaches of increasing signal resolution: 1) heterodyne, 2) frequency division, including zero-crossing, and 3) full-spectrum, including time expansion (Table 4).

Heterodyning reduces the frequency of the signal from the microphone by mixing it with a synthesized tone (Andersen and Miller 1977). This mixing produces an output signal with a frequency based on the frequency difference between the 2 mixed signals (i.e., the beat frequency). The frequency of an artificially generated signal is set by the user by tuning the detector to listen for calls at a particular frequency. Heterodyne units are the simplest ultrasound detector to

**Table 4.** Methodologies used for ultrasonic bat detection.

| Technique | Information obtained | Strengths | Weaknesses |
|---|---|---|---|
| Heterodyne | Bat activity as indicated by bat passes | Relatively inexpensive<br>Sensitive | Labor-intensive monitoring<br>Should be performed manually<br>Requires multiple units for broadband coverage<br>No effective species discrimination |
| Zero-crossing frequency division | Bat activity as indicated by bat passes<br>Some species discrimination | Low data burden<br>Bat passes automatically registered as separate files<br>Software tools available for processing | Incomplete information content of signals<br>Limited species discrimination |
| Full-spectrum time expansion | Bat activity indicated by bat passes<br>Near complete species discrimination | Bat passes automatically registered as separate files<br>Software tools for processing<br>Automated species discrimination on the horizon | High data burden<br>Bat passes can be missed if data is acquired by time expansion rather than high-speed data acquisition |

implement and typically have excellent sensitivity. Although they produce a signal that allows detection of bat presence, they only render a distorted version of the original signal and the operating principle limits the detection to a narrow bandwidth of about 10–15 kHz above and below the tuned frequency. Combining ≥2 heterodyne units can cover a broader bandwidth, but this increases complexity and there are no existing practical digital recording solutions or computerized analysis systems available to support this approach.

Frequency division reduces the original data generated by sampling at high frequencies needed to interpret ultrasound (a sampling rate of 300,000 signals/sec is required to render a 150-kHz signal). Frequency division can be a numeric division of cycles (e.g., a divide-by-10 approach) that retains amplitude and multiple-frequency information as with a Pettersson D230 detector (Pettersson Electronik AB, Uppsala, Sweden), or this information can be deleted, thus distilling the original to the basic time-frequency domain of the signal's most dominant frequency, as is done with the rapid processing zero-crossing algorithm. Zero crossing is the operating principle used by Anabat detectors (Titley Electronics, Ballina, New South Wales, Australia).

The data reduction of zero crossing accomplished by the Anabat system makes it a practical choice for long-term monitoring projects. A single Anabat unit may generate only one megabyte (MB) of data per night. However, lacking fine-scale resolution essential for discriminating many species, acoustic data generated from Anabat detectors are suitable for monitoring presence and activity patterns, and species identification for some (varies by species and region). More rigorous species discrimination may be accomplished with supplemental full-spectrum acoustic data or by capture methods.

Full-spectrum acoustic data retains the full information content of the signal (i.e., time, multiple frequency content, and signal amplitude) and is thus suitable for detailed bioacoustic analysis including recording of calls for playback experiments, digital signal analysis, and acoustic species identification (Parsons and Szewczak 2008). Playback of full-spectrum recordings at a reduced speed or time expansion (e.g., by a factor of 10) renders a 40-kHz ultrasonic signal as an audible 4 kHz and facilitates recording and data storage using standard audio equipment. Time expansion does not alter the information content of the signal. Pettersson model D240x and D1000x ultrasonic detectors are examples of this type. The rich information content of full-spectrum data generates a large amount of digital data, upward to 100–500 MB of data per night depending on bat activity and data compression (Preatoni et al. 2005).

*Acoustic monitoring of bats at wind-energy projects.*— Acoustic monitoring of bats at wind-energy projects is best considered in the context of pre- and postconstruction surveys. Activity of bats can be assessed at proposed wind-energy facilities by determining the presence and activity levels and potential temporal events of high activity (e.g., migratory pulses and swarming activity). Ideally, acoustic monitoring should be conducted at the site of each proposed wind-energy facility, although practical limitations prevent coverage at all potential turbine sites. The Alberta Bat Action Team recommended a minimum number of preconstruction monitoring stations placed at each north, east, south, and west periphery of a proposed project area, with one station in the center (Lausen et al. 2006); however, we suggest additional stations be placed in the vicinity of any variations in terrain, especially those that may potentially serve as a flyway (e.g., a forest gap). Alternatively, a systematic sample of the area of interest is recommended with a random starting point along the axis of the wind resource area.

If a 3-dimensional sample survey using a vertical array of bat detectors is deployed (Fig. 13), a grid could be placed over the wind resource area with some systematic selection rule. For example, the minimum number of detectors for a site with 5 turbines would require deployment of 15 bat detectors. For larger projects, more detectors would be needed. An initial site assessment using bat detectors may yield little or no evidence of bat activity at a proposed wind development area. However, thorough temporal sampling

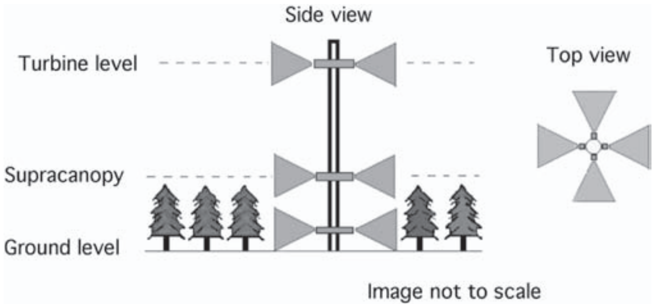


**Figure 13.** Schematic model showing a vertical array of ultrasonic bat detectors attached to meteorological towers used for assessing nightly migratory and foraging activity of echolocating bats from ground level to the height of the turbine nacelle. (D. S. Reynolds, North East Ecological Services, unpublished data).

**Figure 14.** Temporary (portable) tower used for a preconstruction acoustic survey at the Casselman River Wind Project, Somerset County, Pennsylvania, USA. Although the tower extends to the local tree-canopy height, bat foraging behavior and activity will likely change markedly when the forest is cleared for construction, creating edge habitat and open space that is not present during the preconstruction period (E. B. Arnett, Bat Conservation International, unpublished data).

would be needed to assess the existence of possible seasonal pulses of activity from migration. With current understanding of bat biology, it is difficult and largely indefensible to conclude that the absence of bat activity on one or a few nights of recordings (as might be typical of a preconstruction survey) supports the appropriateness of a given site for wind facility development.

Given their limitations, ultrasonic detectors placed at ground level cannot detect bats at the rotor height of modern utility-scale wind turbines. Because bat fatalities recorded to date are thought to result mostly from direct strikes by turbine rotors (Horn et al. 2008), it is essential to deploy detectors at the height of the rotor-swept area to effectively assess potential flight activity through the relevant airspace. This height will vary according to the size of the turbine, but where possible, detectors should be deployed $\geq$30 m above the ground to adequately assess flight activity of temperate insectivorous bats. Where possible, detectors should be placed at existing meteorological towers, which are typically available at both preconstruction and postconstruction wind-energy facilities (Reynolds 2006). In the absence of such structures, temporary towers can be deployed (Fig. 14). In addition to detectors placed at rotor-height, each monitoring location should also have a detector placed near ground level (2–3 m agl) to optimize the volume of airspace for detecting bats, because at this height the detector reception will reach ground level and also detect flying bats flying above it, at least in the range limits of detection. A third detector deployed at an intermediate height would more effectively cover the vertical distribution of expected bat activity. Ground-level detectors will assist in assessing bat presence, and rotor-height detectors will assess potential interactions of bats with rotors (Reynolds 2006).

A lack of documented bat activity at rotor-height during preconstruction surveys does not preclude risk of collision, because bats may be attracted to a site once turbines are constructed (Ahlén 2003, Kunz et al. 2007, Arnett et al. 2008). Thus, surveys at ground level may only serve to indicate presence of bats that could potentially become attracted to the height of operating wind turbines. Alternatively, changes in vegetation cover and conditions from preconstruction to postconstruction may also affect the height at which bats fly, thus leading to more bats feeding, commuting, or migrating through an area, and potentially increasing exposure risk with turbine rotors.

Reynolds (2006) deployed a vertical array of acoustic detectors on meteorological towers that recorded continuously for several nights during the spring migration period at a proposed wind facility in New York. More recently, 2 other studies have deployed detectors at multiple levels on the available meteorological towers and remotely monitored bat activity for several months (Arnett et al. 2006, Redell et al. 2006). Establishing vertical arrays of detectors to allow sampling near or within the rotor-swept area is desirable and recommended by all entities requesting such information for preconstruction studies.

Unfortunately, only a few (e.g., 1–3) meteorological towers are available at most wind-energy projects, which severely limit the ability to distribute sampling points in vertical arrays in any given project. The number of sampling points required to achieve a desired level of precision for describing activity and species composition at a proposed site is currently unknown, owing in part to the relatively small datasets gathered to date. A preliminary analysis of data gathered at meteorological towers and supplemental portable towers in Pennsylvania (Arnett et al. 2006) suggests that 2 or 3 towers typically monitored with detectors during preconstruction studies may fail to adequately represent bat activity on a given site (M. Huso, Oregon State University, unpublished data). Moreover, the number of towers required to reliably predict postconstruction fatality remains to be determined and likely will vary depending on the size of the proposed development.

Despite its limitations, acoustic detection of bats provides a practical and effective means to assess relative activity of

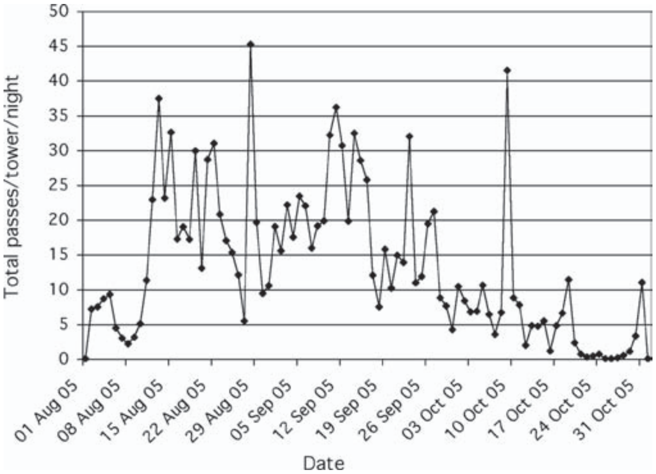


**Figure 15.** Sample data from a preconstruction acoustic survey conducted at the Casselman River Wind Project, Somerset County, Pennsylvania, USA (1 Aug–1 Nov 2005) showing total number of bat passes per tower per night. These pooled data suggest a potential migratory pulse during October that invites further evaluation on a tower-by-tower basis to assess potential migratory flyways (modified from Arnett et al. 2006).

species that can be identified. Acoustic detectors should be deployed in vertical arrays, with ≥2 levels (at 1.5–2 m above ground and as high as permitted by existing meteorological towers), preferably 3 levels, on all available towers. Sampling additional points with portable towers may be necessary to achieve sufficient spatial replication at a development site. Detailed guidelines for detector deployment and operation are reported elsewhere (Arnett et al. 2006, Reynolds 2006).

Postconstruction acoustic surveys can be used to support carcass surveys and provide information on changes in baseline activity acquired during preconstruction surveys. These data would help verify estimates of risk made during preconstruction monitoring and could aid in assessing success of mitigation measures. Postconstruction monitoring could also reveal unanticipated impacts from project-related changes (e.g., clearing of a forested area). Increased detection of fatalities from carcass surveys may also provide justification to heighten the level of postconstruction acoustic monitoring as a means of evaluating causes and consequences.

By convention, most acoustic surveys of bat activity report mean passes per detector-hour or mean passes per detector-night per tower (Fig. 15). For consistency and comparison, detector-hours should be normalized to hours past sunset for each date considered. This facilitates pooling and comparing data throughout a season or multiple seasons and years. In addition to assessing overall activity, data should be assessed by date and by detector to recognize temporal or spatial peaks in activity that may indicate particular threats to bats. Specific recommendations for how much activity poses a threat and responsive mitigation and avoidance guidelines remain an area of active research (Arnett et al. 2006).

*Acoustic identification.*—Acoustic identification of bat species poses a greater challenge than would be expected from experience with birds. Unambiguous species recognition using acoustics has remained an elusive goal for many bat researchers. In contrast to birds, whose calls have undergone selection to be different from those of other species, echolocating bats use their calls for acquiring information from the environment (including size, shape, and wing flutter), and in general natural selection has operated to optimize prey detection. For some syntopic species (e.g., *Myotis* and *Eptesicus*–*Lasionycteris*) there appears to be little selective pressure to emit calls differently among species. Based on current technology, many species appear to lack obvious discriminating differences in their vocal characteristics (Betts 1998, Barclay 1999, Szewczak 2004, Parsons and Szewczak 2008). As an additional complication, bats exhibit considerable plasticity in their vocalizations and can produce call variants that overlap in many parameters with those emitted by other species (Thomas et al. 1987, Obrist 1995, Barclay 1999).

Despite these challenges and limitations, the basic time-frequency characteristics rendered by zero-crossing (Anabat) processed data generally provides sufficient information to recognize acoustically distinctive species (e.g., eastern red bat [*Lasiurus borealis*] and hoary bat (*Lasiurus cinereus*]) and at the minimum place bats into groups having similar acoustic characteristics (e.g., big brown [*Eptesicus fuscus*] and silver-haired bats [*Lasionycteris noctivagans*], and *Myotis* species, respectively).

High-resolution sonograms processed from full-spectrum data reveal subtle attributes and significantly improve species discrimination of bat echolocation calls (Fig. 16; Parsons and Jones 2000, Fenton et al. 2001, Szewczak 2004). The greater information content inherent in full-spectrum data also supports objective species discrimination using automated computer processing. Parsons and Jones (2000) developed an artificial neural network that correctly identified 87% of the 12 most acoustically difficult bat species in the United Kingdom including a suite of *Myotis* species, compared with the performance of discriminant function analysis on the same data set that gave a correct classification rate of 79%. More recent research applying increased extraction of acoustic parameter and ensembles of computer learning systems have boosted the correct automated classification rate of this same data set to 97% (S. Parsons, University of Auckland, personal communication). Systems applying this methodology to North American bats are currently under development. Our understanding of bat behavior continues to improve with advances in detection technology. For example, ultrasonic microphone arrays and video images could be used to determine the 3-dimensional use of space by bats around turbines (Holderied and von Helversen 2003, Holderied et al. 2005).

*Predicting bat fatalities.*—The preliminary report of an ongoing preconstruction survey by Arnett et al. (2006) provides the first example of a thoroughly designed study involving acoustic monitoring. The study was initiated in mid-summer 2005 as part of a 5-year study to determine patterns of bat activity and evaluate the use of acoustic

Table 5. Fatality and bat activity indices at 5 wind-energy facilities in the United States.

| Study area | Inclusive dates of study[a] | Bat mortality (no./turbine/yr) | Bat activity (no./detector/night) | Total detector nights | Source |
|---|---|---|---|---|---|
| Mountaineer, WV | 31 Aug–11 Sep 2004 | 38.0 | 38.2 | 33 | E. B. Arnett, Bat Conservation International, unpublished data |
| Buffalo Mountain, TN | 1 Sep 2000–30 Sep 2003 | 20.8 | 23.7 | 149 | Fiedler 2004 |
| Top of Iowa, IA | 15 Mar–15 Dec 2003, 2004 | 10.2 | 34.9 | 42 | Jain 2005 |
| Buffalo Ridge, MN | 15 Mar–15 Nov 2001, 2002 | 2.2 | 2.1 | 216 | Johnson et al. 2004 |
| Foote Creek Rim, WY | 1 Nov 1998–31 Dec 2000 | 1.3 | 2.2 | 39 | Gruver 2002 |

[a] Sample periods and duration of sampling varied among studies, with no fatality assessments conducted or bat activity monitored in winter months.

monitoring to predict fatalities of bats at a proposed wind-energy facility in south-central Pennsylvania. The primary objectives were to 1) determine level and patterns of activity of different species groups of bats using the proposed wind facility prior to and after construction of turbines, 2) evaluate relationships between bat activity, weather, and other environmental variables, and 3) determine if indices of preconstruction bat activity can be used to predict postconstruction bat fatalities.

The study plan relied on long-term recording of echolocation calls using Anabat zero-crossing ultrasonic detectors (Fig. 17) with spot-sampling using mist-net captures and full-spectrum acoustic recording. This study used a rotation of temporary towers to sample at a large number of proposed turbine sites. Results from the study will be combined with numerous studies currently underway throughout North America that have deployed acoustic detectors to quantify preconstruction bat activity and will later conduct postconstruction searches to estimate bat fatality. The analysis will evaluate possible relationships between bat activity with postconstruction fatality rates from each facility to determine if fatalities can be predicted from preconstruction acoustic data and at what level of precision.

*Bat fatality and activity indices.*—Five studies have reported on postconstruction surveys using Anabat zero-crossing ultrasonic detectors to support and interpret carcass surveys at operating wind-energy facilities (Table 5). The estimated total number of bat calls per night for each site was positively correlated with estimated fatalities per turbine per year ($r = 0.79$). However, there are several limitations of this type of analysis. The data on echolocation calls reported in these studies did not distinguish among species. Moreover, echolocation calls were recorded at different altitudes at some sites and only at ground level at others. In addition, echolocation call data were all collected after the wind-energy facilities were constructed. Thus, it is unclear whether preconstruction call data would have shown a different pattern. If modifications to forested habitats (thereby creating linear landscapes) or the turbines themselves attract bats, the relationship between preconstruction call rates and fatality rates may not exist or may not be as strong.

## Radiotelemetry

Radiotracking (following animals) or radiotelemetry (transmitting other information in addition to an audio signal with miniature VHS transmitters (Millspaugh and Marzluff 2001, Fuller et al. 2005) has the potential to follow the dispersal and migratory paths of known individual birds or bats for long distances. Radiotracking was pioneered with birds weighing about 35 g in the 1960s (Graber 1965, Cochran et al. 1967) and has been used to 1) study the flight of nocturnal passerine migrants with respect to wind and land features (Cochran and Wikelski 2005), 2) recapture birds for measurements of metabolic rate during flight (Wikelski et al. 2003), and 3) transmit wing-beat information (Diehl and Larkin 1998). Where ground-tracking is impractical (e.g., highly mountainous regions), radiotracking from small aircraft holds promise for determining nightly dispersal patterns and migratory routes of some species. Radiotracking of small bats and birds weighing $\geq$15 g over long distances is currently limited by the size of radiotransmitters (e.g., type of signal, and signal strength and duration, which are limited by battery size). A rule of thumb for radiotracking birds and bats is that radiotransmitters should not exceed 5% of the animal's body mass (Aldridge and Brigham 1988).

Global Positioning System (GPS) receivers and transmitters used with Argos satellites are currently too large to be used on passerine birds and small bats (Aldridge and Brigham 1988, Cryan and Diehl 2008). Although radiotracking has been widely employed to follow movements of bats (e.g., Williams and Williams 1970, Wilkinson and Bradbury 1988, Bontadina et al. 2002, Lacki et al. 2007, Amelon et al. 2008), we are unaware of published accounts of long-range migrations of small, migratory bats determined by radiotracking. Large Old World fruit bats (*Pteropus* spp.) have been radiotracked long distances by aircraft (Eby 1991, Spencer et al. 1991), and by satellite (Olival and Higuchi 2006), and ongoing studies in New York and Pennsylvania have been routinely radiotracking Indiana bats (*Myotis sodalis*) with aircraft as they migrate from their hibernacula to maternity sites (A. Hicks, New York Department of Natural Resources, personal communication; C. Butchkoski, Pennsylvania Game Commission, unpublished data; Fig. 18).

Radiotracking by aircraft is an attractive technique for investigating how known individuals of different species of nocturnal birds and bats use the landscape (e.g., Cochran and Wikelski 2005, Holland et al. 2006). Birds and bats have been followed with vehicles (use of vehicles is limited when roads are poor and when a signal is obstructed by terrain), by fixed-base Yagi antennae placed on ridges, and

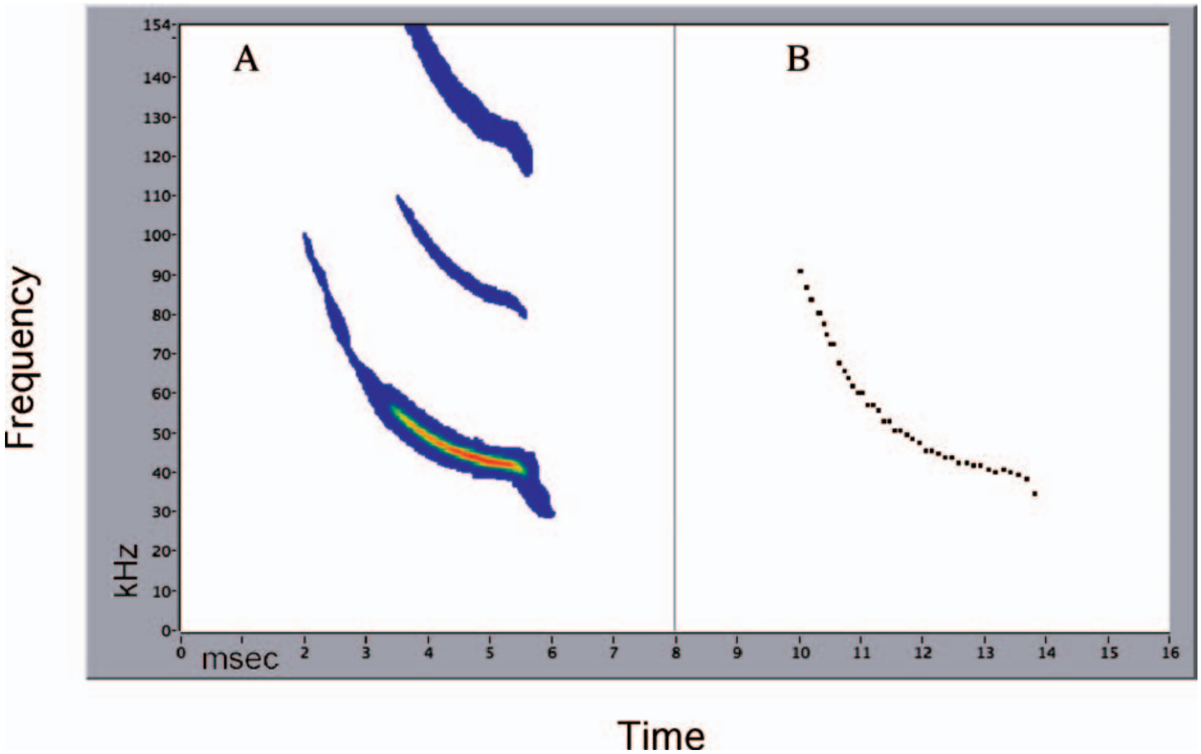


**Figure 16.** Echolocation call recorded from a western small-footed myotis (*Myotis ciliolabrum*) processed from full-spectrum data (A) and rendered with zero-crossing data reduction in the manner of Anabat (B), Birchim Canyon, near Bishop, California, 11 June 2001. The distribution of amplitude with the call, as mapped by color, can aid in discriminating this species from other *Myotis* species with calls in this frequency range. The presence of harmonics is a useful indicator that can aid in discriminating some species such as silver-haired bats (*Lasionycteris noctivagans*) and big brown bats (*Eptesicus fuscus*; J. Szewczak, Humboldt State University, unpublished data).

with aircraft but with high hourly expense and limitations due to Federal Aviation Administration regulations and public safety. In some situations, it may be possible to track nocturnally active birds and bats from fixed-base Yagi antennae positioned on high places in the area under study (Larkin et al. 1996; R. P. Larkin, Illinois Natural History Survey, unpublished data). Such stations arranged in a picket line (string of stations) could be used to follow flight paths of several migrating bats (known individuals and species) across areas such as mountain ridges. A recent proposal to develop a global small-animal satellite tracking system (Wikelski et al. 2007) holds considerable promise for investigating movements of small birds and bats over large temporal and spatial scales. The scientific framework for this project is outlined in the International Cooperation for Animal Research Using Space initiative. If satellite tracking of birds and bats with miniature transmitters becomes possible (Cochran and Wikelski 2005), this will open a new era of logistical feasibility for following nightly and seasonal movements of bats and birds.

## METHODS AND METRICS FOR COLLECTING ADDITIONAL DATA ON NOCTURNALLY ACTIVE BIRDS AND BATS

### Capture Methods

Captures of nocturnally active birds and bats may provide valuable information for assessing and confirming the presence of both resident and migrating species, but special training of personnel is required to capture and remove birds and bats from mist nets. Resident bird and bat species are easiest to capture when they forage near the ground, over bodies of water, or within and beneath the canopy of forests (e.g., Kunz 1973, Kurta 1982, Lloyd-Evans and Atwood 2004). Capturing migrating birds and bats during migratory stopovers can provide valuable demographic information (e.g., relative abundance, condition, age, and sex) needed for assessing population status provided that long-term, consistent, efforts are made (Lloyd-Evans and Atwood 2004, Weller and Lee 2007; T. Lloyd-Evans, Manomet Center for Conservation Sciences, personal communication).

Because many bats fly above the height of ground-based mist nets, surveys should employ both ground-level and stacked canopy nets, especially in forested landscapes and in riparian communities or over water holes (e.g., cattle tanks and ponds) located in agricultural and other open landscapes. Developing a capture history that can be used to estimate probabilities of detection and occupancy (e.g., program PRESENCE; MacKenzie et al. 2001, U.S. Geological Survey 2006) requires multiple visits. A single season, even with multiple visits, does not reliably sample bat assemblages or presence of a single species (Weller and Lee 2007; E. B. Arnett, Oregon State University, unpublished data). Unless multiple capture efforts over multiple years are undertaken, species of bats should not be considered absent or to have low relative abundance at a proposed site. Mist

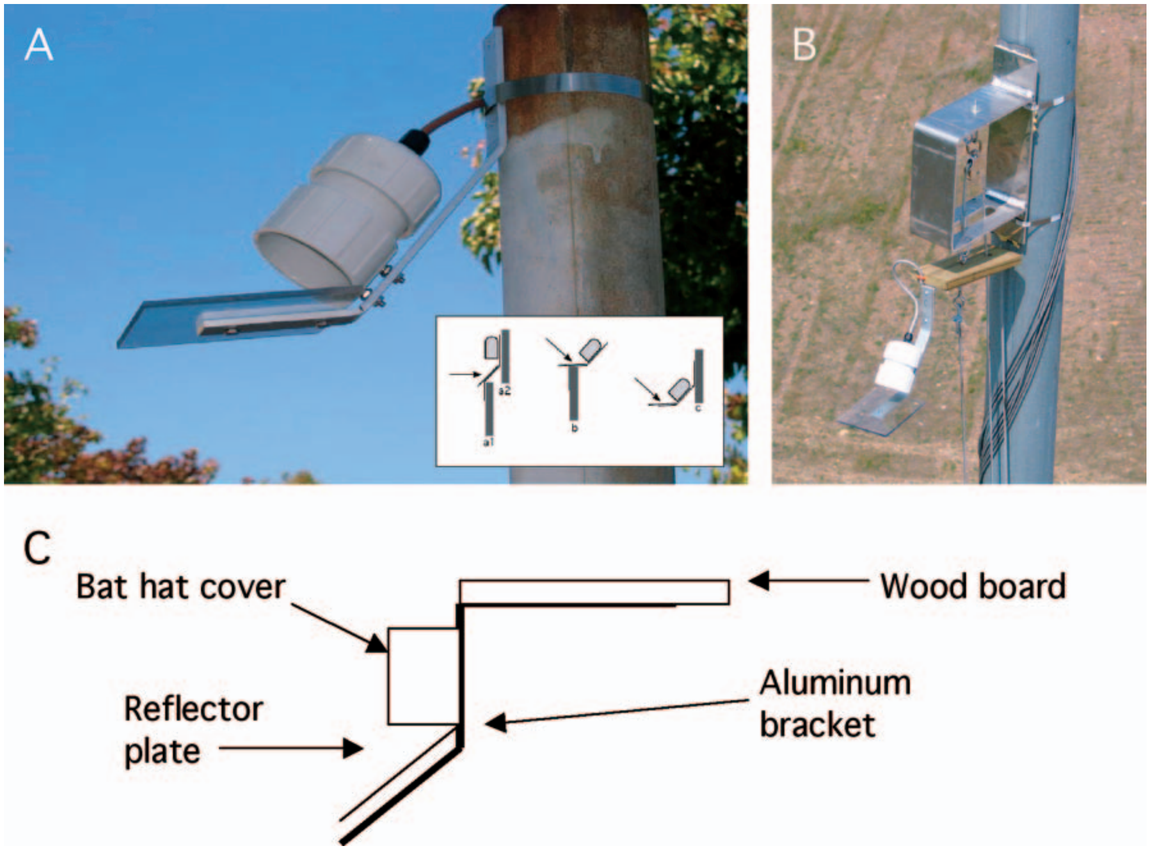


**Figure 17.** A) Anabat microphones protected by a weather-proof bat hats can be deployed and linked by cables to ground-based data-logging units. When installed, the microphone points downward and receives signals from a clear Lucite or Plexiglas reflector. Three optional designs of brackets are shown for mounting bat hats (see inset). B) Remote microphones protected by weather-proof bat hats are mounted on a carriage that is part of a pulley system. When attached to a tethered pole, this configuration enables retrieval and deployment of microphones (using a crane) from the ground following initial installation. C) Schematic diagram of bracket used to mount a bat hat on the pulley system shown in A (E. B. Arnett, Bat Conservation International, unpublished data).

netting used in conjunction with acoustic detectors (Kuenzi and Morrison 1998) may offer a more complete approach to evaluating presence of species at a site.

Devices and methods used to capture birds and bats have been thoroughly discussed elsewhere (see reviews in Kunz and Kurta 1988, Kunz et al. 1996, Braun 2005, Kunz et al. 2008*a*), so only a brief overview of methods is provided here. Although no single capture method is suitable for all species, mist nets for birds and mist nets and harp traps for bats are the devices used most commonly because they are relatively easily deployed and can be used in a variety of situations.

The choice of capture device for bats should be dictated by numbers of animals present or expected at a particular site or expected to emerge from a roost located near proposed or operational wind-energy facilities. In situations during preconstruction surveys at proposed wind-energy facilities, where the local bat fauna and roost sites are unknown, trapping efforts should focus on expected or potential commuting, foraging, drinking, and roosting sites. Prior assessment of local topography, habitat structure (e.g., foliage density), and visual or acoustic surveys using ultrasonic detectors can often aid in the selection of potential capture sites and deployment of appropriate capture devices. Many of the methods used to capture birds and bats are similar—although some differences exist. For example, if bats are to be captured at roost sites to assess the species present in the vicinity of wind-energy facilities, or to monitor changes in colony size, harp traps are preferable to mist nets (Kunz et al. 2008*a*). Most importantly, efforts should be made to minimize disturbance to bat colonies or colonial-nesting birds.

*Mist nets.*—A mist net consists of a nylon mesh supported by a variable number of taut, horizontal trammel lines, or shelf strings. Bats and birds are captured after they become entangled in the mesh of the nets. Mist nets are properly deployed when the horizontal shelf strings that support the net are taut horizontally. The netting material should not be extended to its full extent, but should allow some slack between the shelf strings, to allow the formation of bags (or pockets) into which the bird or bats fall upon encountering the net. A bird or bat is captured in a mist net when it flies into the mesh between the shelf strings, and falls into a net bag from which it generally is unable to escape (Braun 2005, Kunz et al. 2008*a*, *b*).

The type and number of nets, and the manner in which they are deployed, can greatly influence capture success. For most applications, ground-level nets are easiest to deploy, but they may bias the sample of captured birds or bats if some species fly (e.g., commute or forage) high in or above the forest canopy. Use of canopy nets can provide researchers access to the aerial space in forested regions where some bats and birds may forage or roost during migratory stopovers (Fig. 19). Compared to ground-level nets, canopy nets may take longer to deploy, but they have the advantage of covering a larger area of vertical space within or beneath a forest canopy, including areas near the ground (Mease and Mease 1980, Hodgkison et al. 2002).

For detailed information on types and sizes of mist nets, preparation of nets for field use, deployment strategies in different environments, types of net poles, removing bats and birds from nets, and methods for dismantling nets, consult published descriptions (Kunz and Kurta 1988, Ralph et al. 1993, Kunz et al. 1996, Braun 2005, Kunz et al. 2008*a*).

*Harp traps.*—Harp traps are recommended for assessing presence and relative abundance of bats in situations where opportunities for mist netting are ill advised or limited, especially where bats are present in relatively high densities or roost in caves, mines, or buildings near proposed or operational wind-energy facilities. Harp traps have proven successful for capturing bats as they emerge from such roost sites during evening emergence and throughout the night as they periodically return and emerge during intermittent feeding bouts (Fig. 20). These traps consist of one or more rectangular frames, strung with a series of vertical wires or monofilament lines usually spaced about 2.5 cm apart. When a bat hits the bank of wires or lines, it falls into a bag beneath the trap. In situations during preconstruction surveys where the local bat fauna and possible colonies sizes are unknown, harp-trapping efforts should focus on expected or potential commuting, foraging, drinking, and roosting sites.

Personnel assigned to capture bats at wind-energy projects also must secure state and Federal permits to capture and handle birds and bats, especially endangered species. In the case of handling, personnel must be immunized against rabies and wear proper gloves to avoid being bitten. Nets must be tended regularly to avoid injury to captured animals and to prevent damage to nets if too many bats are captured simultaneously. Nocturnally active birds and bats captured at ground level, near roost sites, or in the forest canopy, may not reflect the same composition of species that fly within the rotor-swept area or that are killed during migration.

*Pre- and postconstruction surveys.*—Capture surveys for bats are frequently employed and often required by government agencies, particularly to assess presence of endangered species. However, not all proposed or operational wind-energy facilities offer conditions conducive to capturing bats and often the number of suitable sampling points is minimal. Sometimes netting efforts occur at water sources off-site or harp trapping at nearby roosts, which may not reflect species presence at or use of the actual site where turbines are to be installed.

Mist netting alone may be inadequate for assessing bat activity at proposed and operational wind-energy facilities and, thus, should be considered a low priority in open landscapes such as grassland and agricultural fields (except when birds or bats are active over and near water tanks and reservoirs). Notwithstanding, mist-netting and harp-trapping are the only available methods that can provide reliable information on sex, age, and reproductive condition, and when possible these techniques should be employed as part of pre- and postconstruction surveys. Captures of birds and bats near roost sites and in habitats below and adjacent to wind turbines can provide valuable information on population variables before and following construction of wind turbines, especially for the collection of tissue samples for DNA and stable isotopes, and for assessing demographic population size, genetic diversity, and geographic origins of bats and birds present during resident and migratory periods.

## Estimating Population Size and Genetic Variation Using Molecular Markers

Estimates of population structure, genetic diversity, and demographic and effective population size are important parameters for assessing the dynamics of endangered, threatened, and species of special concern (DeYoung and Honeycutt 2005, Dinsmore and Johnson 2005, Lancia et al. 2005). Estimates of these parameters for both resident and migrating birds and bats are needed to better understand how populations respond to naturally occurring perturbations and anthropogenic factors such as climate change, deforestation, and habitat alteration. Wind-energy development, along with other anthropogenic activities, may have adverse effects on some bird and bat populations by directly causing fatalities and indirectly altering critical nesting, roosting, and foraging habitats. To adequately assess whether fatalities or altered habitats are of biological significance to resident and migrating birds and bats, knowledge of baseline population levels, population structure, and genetic variation are needed. These parameters can be expected to differ among species that are subject to different risks from local and regional environmental factors.

*Estimating demographic population size.*—Historically, estimates of population size of birds and bats have been derived using a variety of methods, including direct counts, point counts, and other estimating procedures such as capture–mark–recapture methods, photographic sampling, probability sampling, maximum likelihood models, and Bayesian methods (e.g., Bibby et al. 2000, Thompson 2004, Braun 2005, Kunz et al. 2008*b*). Notwithstanding, few statistically defensible estimates of population size for birds and bats have been published, especially for migratory tree-roosting bat species (O'Shea and Bogan 2003; O'Shea et al. 2003, 2004). Direct counts often are not practical for most nocturnally active bird or bat species, in part because these animals are typically small, cryptic, or otherwise difficult to visually census using most existing technologies during 1) daily or nightly emergences from roosts, 2) migratory or foraging flights, or 3) migratory stopovers.

*Visual census methods at bat roosts.*—When bat colonies are relatively small <1,000), visual censusing may be practical and potentially less disturbing to the colony than other methods (Kunz and Anthony 1996, Kunz 2003, Kunz et al. 2008*b*). Where large numbers of bats are present at roost sites, censusing protocols using thermal infrared imaging cameras can provide reliable estimates of number of bats present (Sabol and Hudson 1995; Frank et al. 2003; Kunz 2003; Betke et al. 2007, 2008) although repeated sampling is required to assess seasonal changes in abundance and colony composition.

*Genetic sampling.*—Noninvasive genetic sampling can provide valuable information for assessing population parameters of birds and bats at potential risk from wind-energy facilities and other anthropogenic influences. The DNA extracted from skin, hair, feathers, or feces may be used to identify individuals and species, estimate population size, determine sex, identify dietary items, and evaluate genetic diversity and population structure (Thompson 2004, Waits and Paetkau 2005).

Identification of individuals should be the first step when assessing levels of genetic variation within populations. At least 30 individuals from a study population should be genotyped, with 10–25 microsatellite loci. Individual identification based on genetic samples can be used to obtain population estimates based on the minimum known alive or estimates based on mark–recapture methods. Waits and Paetkau (2005) provide technical advice for accurate and efficient collection of genetic data for identification of species, sex, and individuals. Hair and wing tissue (for bats) and feathers and blood (for birds) are the most commonly used sources for noninvasive sampling.

Analysis of mitochrondial DNA (mtDNA) is used for species identification and nuclear DNA (nDNA) is used for individual and sex identification. The DNA extracted from feather samples can be derived from cells attached to the roots of feathers (Smith et al. 2003). Wing biopsies are the most common source of DNA for bats (Worthington Wilmer and Barratt 1992). In these situations, samples for DNA analysis can be collected from live or recently killed birds or bats. Extraction of host DNA from fecal samples is more challenging, and there is no consensus on the most appropriate method to use (Waits and Peatkau 2005).

Capture–mark–recapture models have been used to estimate population sizes derived from genetic samples (Waits 2004, DeYoung and Honeycutt 2005). Using this approach, Puechmaille and Petit (2007) compared estimates of colony sizes of the lesser horseshoe bat (*Rhinolophus hipposideros*) based on DNA extracted from feces with independent estimates of colony size derived from nightly emergence counts. Their results indicate that analysis of DNA can provide accurate estimates of colony size even when feces are collected during a single sampling session.

*Estimating effective population size.*—Estimates of effective population size ($N_e$) also can be derived from genetic markers. Effective population size provides information on how fast genetic variation is being lost or relatedness is increasing in a population of interest (Leberg 2005). Knowledge of $N_e$ is critical for assessing and managing threatened and endangered species or those of special concern because it provides information on how rapidly a population is losing genetic diversity. Thus, reductions in $N_e$ also are related to reduced population variability. Comparisons of historic and contemporary $N_e$ can be used to assess whether a population is declining (Leberg 2005) and, thus, impacts of anthropogenic-related factors (e.g., fatalities at wind-energy facilities) on the genetic future of populations can be assessed (Lande and Barrowclough 1987).

Large populations typically accumulate more genetic diversity and retain this diversity longer than do small populations (DeYoung and Honeycutt 2005). Because these effects are predictable, it is possible to estimate long-term effective population size based solely on observed patterns of DNA diversity. If a population changes in size, predictable effects on patterns of diversity occur, and these effects are proportional to that change. Thus, significant declines in population size through time can be documented, although there is some time lag between changes in population size and observable effects on genetic diversity. A conceptual description of the coalescent process that results in these effects is provided below. More detailed descriptions and applications are found in Luikart et al. (1998), Roman and Palumbi (2003), Avise (2004), Russell et al. (2005), DeYoung and Honeycutt (2005), and references cited therein.

The genetic variation at any particular gene in a population can be illustrated as a topology or gene tree reflecting the historical relationships or genealogy of the gene copies found in different individuals. The number of mutations (i.e., nucleotide substitutions) separating these variable DNA sequences is a function of the demographic history of the population. Because mutations accumulate through time, sequences that diverged longer ago will be separated by a larger number of mutations than those that diverged more recently. If a historically large population remains large, its gene trees will have many branches of varying lengths that reflect the accumulation and retention of older and younger mutations. If a large population is reduced in size, its gene tree will be pruned. That is, genes reflecting both long and short branches will be lost with the result of less overall diversity. Short branches also will be proportionately fewer in the reduced population because fewer recent mutations occur and they are less likely to be retained because of the smaller population size. Correspondingly, if a population that was historically small expands in size, its gene tree will consist mostly of short branches reflecting the increased occurrence and retention of more recent mutations.

It is important to understand the extent of population-level structuring because it can differ markedly among species (DeYoung and Honeycutt 2005). For example, population genetic studies on the Brazilian free-tailed bat (*Tadarida brasiliensis*) show high levels of genetic diversity and little population-level structuring (Russell and McCracken 2006), whereas other species, such as the lesser long-nosed bat (*Leptonycteris curasoae*), show relatively low levels of genetic diversity and high population structuring.

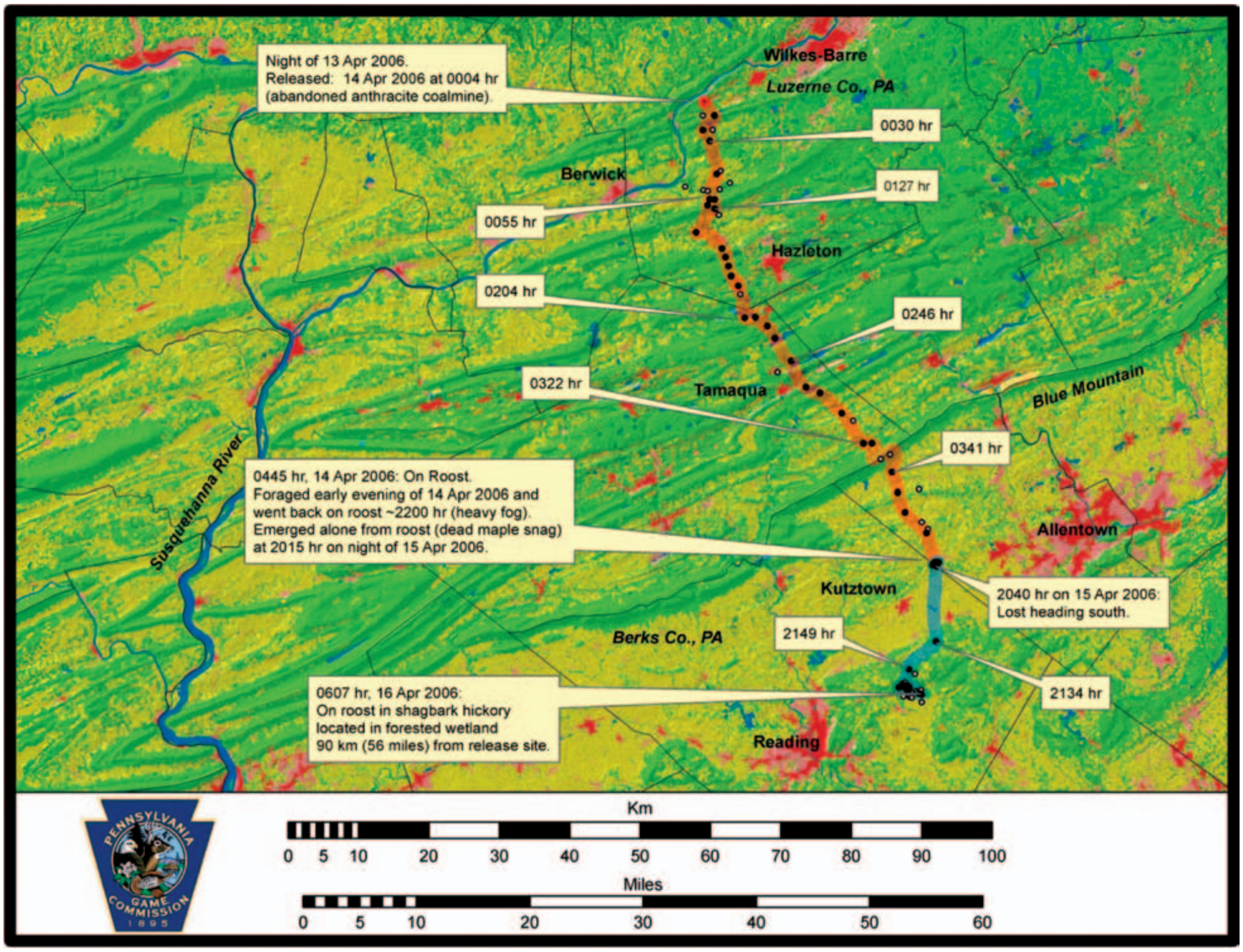


**Figure 18.** Migration route of an Indiana bat (*Myotis sodalis*) over forested ridge tops in western Pennsylvania, USA. This bat was captured and released at an abandoned coal mine at 0004 hours on 14 April 2006. It was tracked by aircraft traveling in a southeasterly direction, settling in a dead maple snag at 0445 hours. In the early evening of 14 April it foraged briefly and returned to its roost at 2000 hours (due to heavy fog). It emerged from its roost tree at 2015 hours on night of 15 April, but at 2040 hours it was temporarily lost while traveling south (near Kutztown, Berks County). On 16 April it was located roosting in a shagbark hickory (*Carya ovata*) tree in forested wetland 90 km from its release site (C. M. Butchkoski and G. Turner, Pennsylvania Game and Fish Commission, unpublished data).

The implications of these and other studies using molecular markers (Avise 1992, 2004) indicate that different species are subject to different risks from anthropogenic influences and should be studied to assess whether a given species is more or less at risk from changing environments. Sex ratios, effective population size, and genetic diversity are intimately linked. Changes in sex ratios in populations can cause changes in effective population size, and when effective population size decreases, populations tend to lose genetic diversity. Loss of genetic diversity can lead to loss of fitness (DeYoung and Honeycutt 2005).

Estimates of effective population size based on genetic diversity have been applied to a variety of birds and mammals to investigate patterns of change caused by human intervention (DeYoung and Honeycutt 2005). For example, the historical population sizes of humpback (*Megaptera novaengliae*) and fin whales (*Balaenoptera physalus*) prior to hunting by humans were estimated to consist of approximately 240,000 and 360,000 whales, respectively, contrasted to modern population sizes of 10,000 and 56,000 individuals, respectively (Roman and Palumbi 2003). The historical estimate of the effective population size of the gray wolf (*Canus lupus*) prior to human settlement of North America was estimated at approximately 5,000,000, as compared to the current estimate of 173,000 (Vilà et al. 1999). For bats, coalescent analysis indicates an expansion of migratory populations of Brazilian free-tailed bats approximately 3,000 years ago, a date that corresponds with the development of a wetter climate and increased insect availability (Russell et al. 2005, Russell and McCracken 2006). This was apparently followed by an approximately 16-fold decline in estimated population size in more recent times, postulated as a consequence of human activity (Russell et al. 2005, Russell and McCracken 2006).

For the lesser long-nosed bat, the most recent estimate of effective population size was 159,000 individuals (Wilkinson and Fleming 1996). These and other estimates of effective population size reflect the current distributional range of a given species. However, census data on populations also are needed when evaluating cumulative impacts resulting from anthropogenic changes. For example, current estimates of colony sizes for Brazilian free-tailed bat,

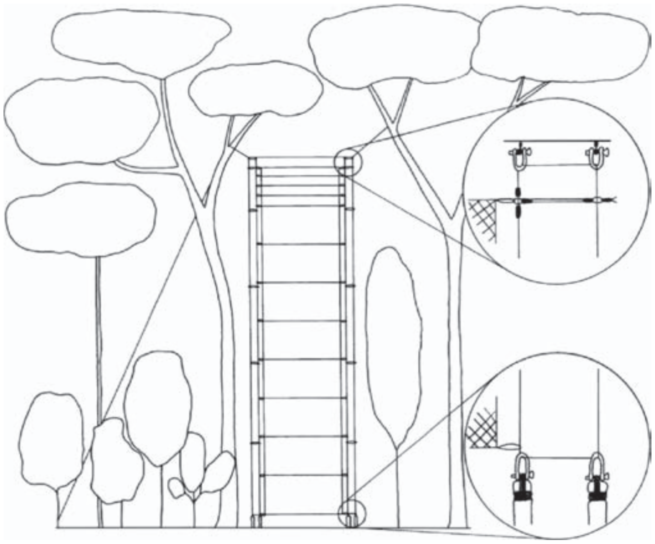

**Figure 19.** Multiple stacked horizontal mist nets used for capturing bats and birds from ground level into the forest sub-canopy (from Hodgkison et al. 2002).

based on thermal infrared imaging and computer vision technologies, emphasize the importance of establishing baseline levels and for conducting long-term studies for assessing real and projected impacts on local and regional populations (Betke et al. 2008; N. I. Hristov and T. H. Kunz, Boston University, unpublished data).

Migratory tree-roosting bats are especially challenging organisms to census, largely because they are solitary and roost in foliage (eastern red bats and hoary bats) or tree cavities (silver-haired bats; Carter and Menzel 2007). Instead of using traditional marking methods, molecular markers could be used to estimate population sizes after identifying individuals from the DNA obtained noninvasively from samples of feces, hair, or skin tissue. As with traditional methods, the reliability of population estimates based on molecular methods makes certain assumptions (DeYoung and Honeycutt 2005). For example, population size can be under- or overestimated if scoring errors are made when the alleles of heterozygous individuals are not amplified during a positive polymerase chain reaction (PCR), or PCR-generated alleles create a slippage artifact during the first cycles of the reaction (Waits and Leberg 2000). Errors of this type can be corrected by repeating the process of genotyping and comparing genotypes to each other (Paetkau 2003).

There are several potential limitations in using genetic sampling to estimate population parameters from both mtDNA and nDNA markers, including contamination of field samples, identifying enough loci to establish adequate resolution sufficient to distinguish individuals, and genotyping errors. If sufficient data are not collected for an adequate number of loci, then the number of individuals in the population will be underestimated. Increasing the number of loci, with improved resolution, also increases the probability of observing genotying errors.

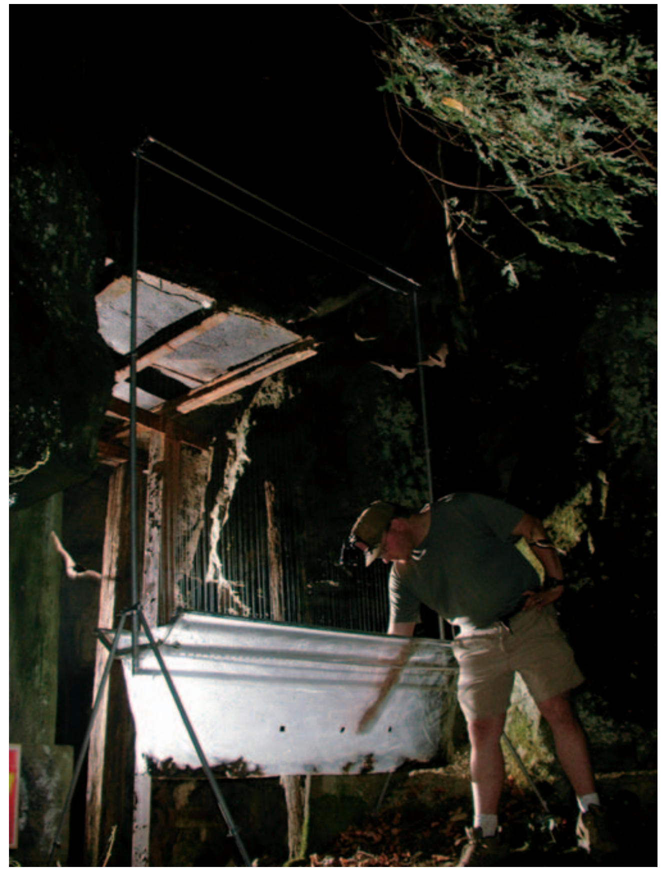

**Figure 20.** Harp traps can be used to successfully capture bats as they emerge from or return to roosts such as buildings, caves, and other similar structures (J. Chenger, Bat Conservation and Management, Inc., unpublished data).

### Assessing Geographic Origins of Resident and Migrating Birds and Bats Using DNA and Stable Isotopes

Knowledge of geographic patterns of stable isotopes of hydrogen (deuterium [D]: hydrogen [H]) has proven valuable for assessing patterns of migration for some bird and bat species (e.g., Meehan et al. 2001, Cryan et al. 2004, Rubenstein and Hobson 2004, Hobson 2005, Cryan and Diehl 2008). This knowledge is made possible because isotopic signatures present in precipitation are transferred directly or indirectly from green plants to consumers (e.g., insects, birds, and bats).

No other element (except oxygen, which is highly correlated with hydrogen) exhibits such consistent patterns of geographic distribution. The stable isotope ratio of hydrogen, $\delta D$ ($\delta D = \left[\frac{(D/H)\text{sample}}{(D/H)\text{reference}}\right] \times 10^3$), in precipitation is inversely related to latitude, elevation, and distance from the coast across all continents (Rozanski et al. 1993, Cryan and Diehl 2008). Following shifts in $\delta D$ between precipitation and primary producers, isotopic signatures typically change systematically across trophic levels (Birchall et al. 2005). Thus, during postnatal growth and molt, $\delta D$ values of animal tissues are correlated with the hydrogen isotope ratios of local precipitation ($\delta D_p$; Hobson and Wassenaar 1997). The relationship between $\delta D_p$ and the $\delta D$ values in animal tissues has made it possible for researchers to infer the geographic origins of migratory animals by comparing tissues collected at different seasons and in different parts of their range (Chamberlain et al. 1997, Hobson and Wassenaar 2001, Meehan et al. 2001, Cryan and Diehl 2008).

Kelly et al. (2002) used stable isotopes of hydrogen extracted from the feathers of breeding, migrating, and wintering Wilson's warblers (*Wilsonia pusilla*), and found that δD values were positively and significantly correlated with latitude of collection, indicating that δD values in feathers provided a good descriptor of the breeding latitude. Cryan et al. (2004) also used stable isotopes of hydrogen to infer migratory movements of hoary bats in North America. Using data collected from feather samples, several studies have used both stable isotope and genetic markers to evaluate migratory habits of birds (Clegg et al. 2003, Royle and Rubenstein 2004, Hobson 2005, Kelly et al. 2005, Smith et al. 2005).

The primary limitations of using stable isotopes for assessing migration of birds and bats is that the stable isotope of hydrogen can vary locally, based on differences in precipitation and ground water. Thus, when tissues are collected from birds or bats, samples of precipitation and ground water should be collected at the same time to improve the geographic resolution of isotopic ratios (L. I. Wassenar and K. A. Hobson, Environment Canada, personal communication). Currently, the resolution of isotope ratios of hydrogen in precipitation is relatively crude with respect to latitude, longitude, and altitude, and it may not be possible to precisely identify source areas of breeding birds or bats within a small geographic region. Gannes et al. (1997) appropriately pointed out the importance of validating assumptions when using stable isotopes and calling for laboratory experiments to validate methods.

*Collecting tissue samples for DNA and stable isotope analysis.*—Living or dead bats collected at or in the vicinity of wind-energy facilities can provide invaluable data for advancing knowledge about the geographic source and abundance of resident and migratory populations. Tissue (via wing biopsies) collected from bats (Worthington Wilmer and Barratt 1996) and blood or feathers from birds (Smith et al. 2003, Waits and Paetkau 2005) can be used for analysis of genetic variation, population structure, for potentially assessing population size using DNA markers, and for assessing the geographic origin of migrants based on stable isotope and genetic analysis. Date, location, species, sex, age, reproductive condition, and standard external measurements for each live, dead, or moribund bird and bat captured or recovered should be recorded.

Use of mtDNA and nDNA sequence data derived from birds and bats killed by wind turbines also offer the potential for identifying closely related or cryptic species. For example, many species of *Myotis* are difficult to identify from either external morphological characters or echolocation calls, yet they can be identified using unique DNA markers (e.g., Bickham et al. 2004, Stadelmann et al. 2007).

*Developing collaborations.*—Collaborations with researchers experienced in genetic and stable isotope analyses are highly recommended. Carcasses should be collected in part or in their entirety and deposited as voucher specimens in research laboratories associated with universities and natural history museums. In the United States, the American Museum of Natural History, New York, serves as a repository for tissues collected from dead or living bats recovered from beneath wind turbines or collected alive (http://research.amnh.org/mammalogy/batgenetics/; contact N. B. Simmons, American Museum of Natural History). The Conservation Genetics Research Center, Center for Tropical Research, University of California, Los Angeles serves as a repository for feather samples from which stable isotope and genetic analysis of birds can be conducted (http://ioe.uclla.edu/CTR/cgrc.html; contact J. Pollinger, University of California, Los Angeles).

## CONDUCTING PRE- AND POSTCONSTRUCTION MONITORING

Many of the methods and metrics summarized above for monitoring nocturnally active birds and bats have been applied during pre- and postconstruction monitoring and research efforts. In this section, we describe basic approaches and protocols to perform pre- and postconstruction monitoring and research, discuss factors influencing and limiting protocol development and implementation, and offer considerations for future monitoring and research.

### Preconstruction Studies

Preconstruction assessments at proposed wind-energy facilities generally are initiated from early project evaluations in consultation with state or Federal agencies with respect to wildlife, including potential direct impacts to bird and bat species, especially nocturnal migrants, and threatened and endangered species or species of special concern. Agencies generally request that data be used to characterize wildlife resources in the context of a proposed development, to evaluate the potential impacts from such development, and to the greatest extent possible, determine the location of turbines that will minimize risk to birds and bats. Although these objectives may provide useful information for designing a facility and siting specific turbines, or perhaps aiding in the decision to abandon a project altogether, each project may require a different sampling design, level of sampling intensity, and volume of data to be collected.

Multiple factors may influence preconstruction monitoring and confidence of the data collected as outlined in the original "Methods and Metrics" document (Anderson et al. 1999), as well as other works (e.g., Skalski 1994, MacKenzie et al. 2001, Morrison et al. 2001, Pollock 1991, Pollock et al. 2002). Designing a preconstruction study protocol should begin with clearly defined questions. Thus, a clear understanding of the relevant questions should dictate the sampling design and methods. An inappropriate protocol may result in low power to detect differences (Steidl et al. 1997), failure to account for spatial and temporal variation (Hayes 1997), and pseudoreplication (Hurlbert 1984), all of which can lead to unreliable statistical and deductive inferences. Ultimately, when assessing risks to nocturnally active birds or bats at a proposed wind-energy site, failure to design an appropriate sampling protocol and account for the aforementioned factors may increase the likelihood of a Type II error (i.e., failing to reject a false null hypothesis and concluding no effect when, in fact, there is one).

A fundamental gap in our current knowledge of preconstruction assessment of risk is that no linkages exist between preconstruction assessments and postconstruction fatalities for nocturnal wildlife. Although intensive studies are underway (Arnett et al. 2006), it may be several years before methods described in this document can be used to predict fatalities with an acceptable level of precision, accuracy, and degree of confidence.

In the case of Federally endangered species, the course of action for decision-making is reasonably well-defined. For example, a developer who finds Indiana myotis (*Myotis sodalis*) during mist-net surveys on a project area may enter into voluntary negotiations with the United States Fish and Wildlife Service (USFWS) to receive an incidental take permit under the auspices of a Habitat Conservation Plan under Section 10 (a)(1)(B) of the Endangered Species Act or may chose to abandon the project due to high risk of taking additional endangered species (U.S. Fish and Wildlife Service 2003).

Currently, there is neither a framework nor empirically driven guidelines for agencies or developers to know what 39.7 ($\pm$3.1 SD) bat calls per night gathered with acoustic detectors or a passage rate of 116.9 ($\pm$8.6) targets/km/hour collected from radar actually mean compared to 119.1 ($\pm$26.2) bat calls per night or 350.7 ($\pm$77.1) targets/km/hour, except that the activity and variance is about 3 times higher in both cases. Thus, establishing linkages between preconstruction metrics and postconstruction fatality estimates is a vital next step toward being able to predict impacts and, thus, provide the context needed for decision-making. Until additional empirical data are gathered and a relationship between independent variables and the number of fatalities, establishing decision-making criteria will be far more challenging, controversial, and politically charged than improving the sampling designs and quality of information gathered. Considerable uncertainty and risk reside in existing decision-making frameworks, but to best utilize the information gathered during the preconstruction period, such frameworks are needed for stakeholders to agree upon and implement. Established quantitative criteria for decision-making should be based on the best available scientific information and subject to change as new information is gathered, following the fundamental principles of adaptive management (Holling 1978, Walters 1986).

**Postconstruction Studies**

Many of the methods and metrics described for preconstruction surveys may be used effectively during the postconstruction period, including visual, acoustic, radar, and capture methods. In addition, postconstruction studies require estimates of actual bird and bat fatalities.

*Estimating presence and activity.*—With few exceptions, postconstruction monitoring has centered on fatality searches. Five postconstruction studies have deployed ultrasonic detectors to record bat activity at operating wind facilities (Gruver 2002, Johnson et al. 2003, Fielder 2004, Jain 2005, Arnett et al. 2006). However, only one study in North America has used thermal imaging cameras to observe bat behavior and interactions with turbines (Horn et al. 2008). Efforts to deploy multiple tools (e.g., acoustic detectors, radar, and thermal imaging cameras) at proposed wind facilities, or those currently operating, are underway in an attempt to test various methods for evaluating preconstruction activity of birds and bats and establishing relationships between flight activity and fatalities (D. Redell, Wisconsin Department of Natural Resources, unpublished data; R. M. R. Barclay and E. Baerwald, University of Calgary, personal communication; A. Kelly, personal communication).

Postconstruction studies using multiple tools (e.g., acoustic detectors, radar, night-vision devices, and thermal infrared cameras) are needed to determine the context and relative exposure of nocturnal animals using the airspace in relation to observed fatalities. Numerous reports and environmental impact statements argue that fatalities of bats at wind-energy facilities are lower in the western United States and within agricultural regions, for example, compared to forested ridge tops in the eastern United States. However, fatalities could be proportionally the same in relation to regional populations or simply the numbers of animals using the airspace at the time fatalities occur. Until this context is established, we suggest that comparisons and extrapolations among regions, especially when varying methods are employed, be viewed cautiously.

*Fatality assessment.*—Experimental designs and methods for conducting postconstruction fatality searches are well-established (Anderson et al. 1999, Morrison et al. 2001). Although the statistical properties for at least some common estimators have been evaluated and suggested to be unbiased or close to unbiased under the assumptions of the simulations (W. P. Erickson, WEST, Inc., unpublished data), important sources of field-sampling bias should be accounted for to correct estimates of fatalities. Important sources of bias include 1) fatalities that occur on a highly periodic basis, 2) carcass removal by scavengers, 3) searcher efficiency, 4) failure to account for the influence of site conditions (e.g., vegetation) in relation to carcass removal and searcher efficiency (Wobeser and Wobeser 1992, Philibert et al. 1993, Anderson et al. 1999, Morrison 2002), and 5) fatalities or injured bats that may land or move outside search plots.

*Temporal distribution of fatalities.*—Most estimators assume that fatalities are uniformly distributed, and at independent random times between search days. However, if the distribution of fatalities is highly clustered, then estimates may be biased, especially if carcass removal rates are high. Most estimators apply an average daily rate of carcass removal expected during the study. If most fatalities

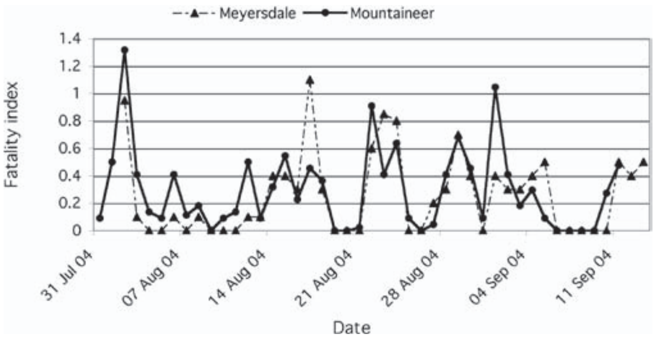


**Figure 21.** Comparison of daily fatalities (no. of fresh bat fatalities/no. of turbines searched) of hoary bats (*Lasiurus cinereus*) and eastern red bats (*L. borealis*) from the Mountaineer Wind Energy Center, Tucker County, West Virginia, USA (31 Jul–11 Sep 2004) and the Meyersdale Wind Energy Center, Somerset County, Pennsylvania, USA (2 Aug–13 Sep 2004). Fatality index is the total number of fresh bats found on a given day divided by the number of turbines searched that day (Kerns et al. 2005).

occur immediately after a search, they would have a longer time to be removed before the next search, resulting in higher scavenging rates than the average rate used in the estimates. This would lead to an underestimate of fatalities. On the other hand, if most fatalities occur before but close to the next search, the fatalities may be overestimated. Potential biases are minimized by ensuring that some searches are conducted most evenings during the survey period and that they are well-distributed throughout the area of interest (Fig. 21).

*Scavenging rates.*—The second source of bias in fatality estimation relates to assessing carcass removal rates by scavengers. All wind-energy facilities will be inhabited by a variety of potential avian (e.g., cervids [Corvidae], vultures [Ciconiidae]), mammalian (e.g., skunks [Mephitidae], raccoons [*Procyon lotor*], and coyotes [*Canis latrans*]), and insect (e.g., burying beetles and ants) scavengers, and searches, especially those conducted at less-frequent intervals, may result in highly biased estimates of fatality (Morrison 2002). Past experiments that have assessed carcass removal using small birds as surrogates for bats may not be representative of scavenging for bat carcasses. Two studies conducted by Erickson et al. (2003) and Johnson et al. (2003) used bat carcasses (estimated to be killed the previous night when found) and found similar or lower scavenging rates on bat carcasses compared to small bird carcasses. However, small sample sizes may have biased estimates and limited the scope of inference of these 2 studies. Fiedler (2004) and Fiedler et al. (2007) conducted 6 bias trials during the first phase of development at the Buffalo Mountain Energy Center in Tennessee and found no difference between bird and bat carcasses for searcher efficiency or scavenging time. Notwithstanding, Kerns et al. (2005), however, reported significantly lower scavenging rates on birds compared to both fresh and frozen bat carcasses at the Mountaineer Wind Energy Center in West Virginia. Scavenging should be expected to vary temporally (e.g., seasonally) and spatially from site to site and among both macroscale habitats (e.g., forests vs. grasslands or agricultural landscapes) and microscale vegetation conditions at any given turbine (e.g., bare ground compared to short grass or agricultural stubble).

*Searcher efficiency.*—It is well-known that searcher efficiency or observer detection (i.e., the rates at which searchers detect carcasses) varies among individuals (Morrison et al. 2001). Searcher efficiency also can be biased by other factors including topography, vegetation, condition of carcasses (e.g., decomposed remains compared to fresh, intact carcasses), weather, and lighting conditions. Searcher efficiency and carcass scavenging should be expected to vary considerably within and among different vegetation cover conditions (Wobeser and Wobeser 1992, Philibert et al. 1993, Anderson et al. 1999, Morrison 2002, Arnett et al. 2008). The use of trained dogs can increase the recovery rate of carcasses, especially in heavy vegetation cover, and offers promise for addressing many questions surrounding bat fatality at wind facilities (Arnett 2006), although dogs undoubtedly vary in their ability to detect carcasses.

*Size of search plots.*—Sizes of plots have varied among studies. Many recent studies used rectangular search plots with edges of plots a minimum distance from the turbine equal to the maximum tip height of the turbine. Observed spatial distributions of fatalities suggest that most, but not all, fatalities occur in this general area. However, topography, maturity of vegetation, size of carcass, wind direction, and other factors likely affect the distribution. This distribution can be used to approximate the number of fatalities missed (Kerns et al. 2005; Arnett et al. 2008; W. P. Erickson, personal communication). Most studies have shown a tighter distribution of bat fatalities around the turbine compared to birds (Kerns et al. 2005). Additional factors affecting the precision and accuracy of fatality estimates include search effort, including the number of turbines searched, intensity of searches within search plots, and the experience of observers (Anderson et al. 1999).

*Search protocols.*—Fatality search protocols have varied considerably among studies. Sampling methods and duration for 21 postconstruction studies conducted in North America are summarized by Arnett et al. (2008). Fatality searches usually are conducted on a systematic schedule of days (e.g., every 1 d, 3 d, 7 d, or 14 d) but rarely have daily searches been employed (Kerns et al. 2005). More intensive searches often are performed during the spring and autumn migratory periods, whereas summer breeding surveys sometimes are less frequent or not conducted at all. By contrast, when they are conducted, most spring and autumn postconstruction carcass searches at communication towers are performed nightly (Manville 2005).

Although there are multiple approaches to performing searches (e.g., line transects, circular plots), any protocol that is used must thoroughly quantify the aforementioned sampling biases to obtain reliable estimates. Most fatality studies to date have poorly accounted for searcher efficiency and removal by scavengers, especially for bats (NRC 2007, Arnett et al. 2008). Some studies adjusted fatality estimates based on a single trial for searcher efficiency and scavenger removal using small samples of bird and bat carcasses, and on $\geq 2$ occasions these trials occurred outside of the migratory periods.

There is a clear need for rigorous implementation of search protocols that can yield reliable estimates of bird and bat fatalities. We recommend that all postconstruction monitoring be designed to address $\geq 2$ common objectives. First, search protocols should be conducted so that estimates of fatalities can be compared across different landscapes and habitats both within and among regions. By standardizing protocols for fatality searches, comparable estimates can be achieved and will be useful for understanding different levels of risk. Search intervals could vary from 3 days to 7 days, as long as standard search methods (we suggest line-transect sampling) are employed and sampling biases (e.g., search efficiency and scavenger removal) are adequately accounted for. The total area searched also should be accounted for and similar visibility classes need to be established (see Kerns et al. 2005).

Second, establishing patterns of fatalities in relation to weather variables, turbine characteristics (e.g., revolutions/min) and other environmental factors is fundamental to understanding wildlife fatality and developing solutions (Kunz et al. 2007). Thus, more intensive (nightly) postconstruction sampling should be conducted at sites where relatively high bat fatalities are expected for $\geq 33\%$ of all turbines, to gather data required to meet this objective. Specific methods and suggestions for establishing and conducting sampling protocols are summarized in Kerns et al. (2005) and Arnett et al. (2008).

## MANAGEMENT IMPLICATIONS

Requirements and implementation of preconstruction monitoring are far less consistent than postconstruction fatality-monitoring protocols. Some states have no requirements for preconstruction surveys, whereas others have minimum requirements to survey for threatened, endangered, or species of concern. However, most available guidelines for assessing potential impacts of wind-energy development on wildlife are voluntary (U.S. Fish and Wildlife Service 2003). With few exceptions, preconstruction studies have been conducted for less than a full year or active season, and some postconstruction surveys have only included a few days or weeks during assumed times of the year when risks may be highest (e.g., migratory periods). Below we provide an overview of methods that we consider important for the study of impacts of wind-energy facilities on nocturnally active birds and bats (Table 6).

### Visual Methods

Night vision goggles and scopes, video cameras, and thermal infrared cameras are valuable tools for monitoring for the presence and activity of nocturnally active birds and bats at wind-energy facilities. Results derived from these tools, combined with appropriate metrics, are important for characterizing activity of birds and bats in both pre- and postconstruction studies associated with wind-energy projects. Deployment of these tools requires adequate knowledge and training of individuals charged with their use and maintenance, the need for periodic calibration, and a full understanding of the limits of detection.

Proper planning and reliable monitoring using visual methods can provide important information about the abundance, frequency, and duration of bat activity in both proposed and operational wind-energy facilities. We recommend that future monitoring studies of nocturnally active birds and bats deploy thermal infrared cameras in concert with acoustic studies to address questions about the postulated causes of bat fatalities at wind turbines. Results from these studies could then be compared with results from other types of monitoring (e.g., radar) to evaluate potential risks to both resident and migrating birds and bats in the vicinity of wind-energy facilities. In particular, thermal infrared imaging holds considerable promise for evaluating the hypothesis that turbines attract bats or insects. For this approach, $\geq 2$ synchronized high-resolution thermal infrared cameras should be used to record the interaction of bats and birds in finer spatial and temporal scales. Such imaging could help researchers visualize, for example, when and how bats interact with stationary and operational wind turbines and, thus, inform owners, operators, and decision-makers how best to develop mitigation strategies.

Chemilumnescent and LEDs have been used successfully for observing the foraging behavior of bats and for validating echolocation calls from different species. Light tags can be used most effectively to observe bats when they fly in open areas, in flyways, and along forest edges and, thus, they may be particularly valuable for assessing bat activity in the vicinity of many wind-energy facilities and for observing responses of flying bats to both stationary and operational wind turbines.

### Radar

Radar is a powerful tool for studying the movement of flying animals. Weather surveillance radars (e.g., NEXRAD) can provide valuable information on broad-scale patterns of migration, colony locations of birds and bats, nightly dispersal behavior, and location of stopover sites for migrating species. However, to obtain passage rates of birds or bats within turbine height (i.e., no. of birds [or bats]/km/hr that are below approx. 125 m agl), we recommend using a marine radar system (to provide passage rates, flight directions, flight path, and altitude information) in tandem with visual techniques (to help distinguish birds from bats). To determine if comparisons can be made among studies from different radars, parallel studies are needed to compare and calibrate the various radar systems, settings, and sampling regimes. Postconstruction studies at wind-energy facilities using carcass searches conducted concurrently with assessments of passage rates using visual and acoustic methods are needed to determine the relationships among passage rates in the rotor-swept zone, weather conditions, and bird and bat fatalities. Limitations of NEXRAD and marine radar include 1) inability to consistently separate migratory birds, bats, and fast-flying insects, 2) inability to determine species identity of most targets, 3) echoes from

**Table 6.** Tools for detecting, tracking, and assessing presence and activity of flying birds, bats, and insects (modified from Larkin 2005).

| Equipment | Range | Identification[a] | Passage rates | Ht information | Cost |
|---|---|---|---|---|---|
| Moon watching | Observer-dependent | + Skilled observers can identify many types of birds and discriminate birds from bats<br>+ Insect contamination rare; butterflies and moths can be identified | 2 d before and 2 d after full moon and with no cloud cover | Very crude | A good telescope of ≥20× is required. Labor-intensive; $2,000/unit |
| Ceilometer (spotlight) | <400 m | − Poor for small targets<br>− Insects can sometimes be confused with birds and bats | Yes, but light may affect flying animals | Very crude | Inexpensive but labor-intensive |
| Night vision (image intensifier) | Good equipment: small birds at 400 m<br>Inexpensive equipment: shorter range | − Inexpensive equipment: poor<br>+ Good equipment: better<br>+ Discriminate birds, bats vs. insects nearby | Yes | Very crude | Relatively expensive if high-quality equipment used: $1,500/unit |
| Thermal infrared imaging cameras | Depends on equipment; can detect some birds at 3 km | Size but not species<br>+ Discriminates birds, insects, and foraging bats<br>+ Migrating birds and bats | Excellent when altitude of target is known | Coarse when calibrated with vertically pointing radar and then used alone | Expensive if high-quality equipment used: >$75,000/unit |
| NEXRAD, Doppler weather surveillance radar | 10–200 km | + Can discriminate targets by speed if winds are known<br>+ Waterfowl and raptors vs. other birds and bats<br>+ Insects slower than songbirds | Good in the infrequent cases where a radar siting is opportune | Very coarse with poor low-altitude coverage | Data are available at no cost; skilled labor for analysis |
| Marine (X-band) radar | 30 m–6 km with proper siting of unit | + Bird and bats vs. insects<br>− Birds vs. bats straight flight: unknown | Good to excellent | Unmodified marine radar antenna in vertical surveillance: yes<br>Parabolic antenna: yes | Specialized; expensive if done correctly<br>Skilled labor for analysis |
| Tracking radar | 100 m–20 km | Vertebrates vs. insects; birds vs. bats in development excellent (stationary beam mode) | Excellent | | |
| Audio microphones for birds | 400 m; depends on ambient noise | + Some nocturnal songbird species<br>+ Data include no insects | Only some species call and quantification is assumption-ridden | Microphones: single: no; arrays: possible | Recording equipment inexpensive, analysis expensive |
| Ultrasound microphones for bats | <30 m; depends on humidity | − Bats may or may not emit sounds<br>+ If they do, may be species-specific | No, only presence–absence<br>Many unknowns at current state of knowledge | Some; depends on microphones and placement | Moderate costs: $2,500/unit |
| Radiotracking | 0–4 km | Excellent | Poor | Crude | High |

[a] + indicates capability, − indicates a lack of capability.

surrounding objects can obscure large parts of the screen, 4) inability to find suitable marine (mobile) radar sampling sites, and 5) difficulty of detecting small birds and bats aloft during periods of heavy precipitation.

**Acoustic Monitoring of Nocturnal Migrating Songbirds**
Recording calls of birds that migrate at night permits identification of many species and similar-sounding groups of species by experienced listeners, but this method does not give a direct indication of numbers or rates of passage. Because the rate of calling varies greatly from night to night, extended sampling periods are needed. To obtain data pertinent to the altitude of birds flying near wind turbines, $\geq$2 microphones are needed to localize the source of calls. The most important practical limitation in assessing bird calls will likely involve interference from ambient sounds at field sites. Advances are being made in sound localization and what determines which species are calling and how often they do so.

**Acoustic Monitoring of Echolocating Bats**
Acoustic detection of bats provides an effective method for assessing bat presence and activity. Because ultrasonic sounds are produced above the range of human hearing, it is important to sample the ultrasound environment prior to establishing a detector placement. A 10-m shift in microphone placement can often make the difference between acquiring useful and useless acoustic data. The ideal recording environment includes anechoic conditions that are thermally homogeneous, without wind, and free from ambient sounds of rustling leaves, falling water, or calling insects. Unfortunately, these conditions are rarely encountered outside of a sound studio and, thus, field-acquired data may be compromised. Successful acoustic monitoring of echolocating bats during pre- and postconstruction periods depend on instrumentation that provides high-quality, distortion-free data. Owing to the limited range of existing ultrasonic detectors, placement of ultrasonic detectors both below and at the height of the turbine rotors will be required to reliably detect presence and activity of bats at proposed and operational wind-energy facilities. Postconstruction studies at wind-energy facilities that include concurrent acoustics monitoring and carcass sampling are needed to determine the relationship among passage rates in the rotor-swept zone, weather conditions, and bat fatalities.

**Radiotracking**
Radiotracking of small, nocturnally active birds and bats using aircraft promises to provide the most valuable information for assessing regional movements and long-distance migration in relation to assessing impacts of wind-energy facilities. Knowing when and where nocturnally active birds and bats navigate over and within natural and human-altered landscapes promises to provide important information that could help guide decision-makers with respect to the siting of wind-energy facilities in order to avoid or minimize risks to both resident and migrating species.

**Capturing Birds and Bats**
At times, it will be necessary to capture birds and bats in the vicinity of wind-energy facilities to confirm the presence of species that cannot be detected by other means. Knowledge obtained from capturing birds and bats in the vicinity of proposed or operational wind-energy facilities, during summer resident periods or migratory stopovers, can provide valuable demographic information needed to assess long-term population trends including possible changes in sex and age ratios, breeding condition, population size, and genetic variation in response to possible adverse impacts of wind turbines. Choice of capture device will be dictated by the taxa of interest, landscape characteristics, and numbers of animals expected at a particular site or expected to return to or emerge from a roost located near proposed or operational wind-energy facilities.

**Collecting Tissue Samples for DNA and Stable Isotope Analyses**
Knowledge of geographic patterns of stable isotopes of hydrogen makes it possible to identify the geographic source of birds in temperate regions by comparing the isotope ratios in precipitation with those found in animals captured or recovered during migratory stopover areas or in over-wintering sites. Dead and injured birds and bats collected at or in the vicinity of wind-energy facilities can potentially provide valuable data for assessing demographic and effective population sizes, genetic variation, and the geographic origin of resident and migratory populations. Carcasses should be collected in part or in their entirety and deposited as voucher specimens in research laboratories associated with universities and natural history museums. Information about carcasses found beneath wind turbines should be recorded with respect to date, location, species, condition, sex, age, and reproductive status. Collaborations with researchers experienced in genetic and stable isotope analyses are strongly recommended.

**Pre- and Postconstruction Monitoring Protocols**
The methods and metrics summarized above provide guidance for monitoring and researching nocturnally active birds and bats at wind-energy projects. Preconstruction assessments should be conducted in consultation with State and Federal agencies, including potential direct and indirect impacts on both resident and migrating birds and bats. Depending upon location, topography, type of vegetation and number of proposed wind turbines, each project will quite likely require a different sampling design, level of sampling, and amount of data collected. A clear understanding of the potential influence of topographic variation, altered land cover, local weather conditions, and other relevant variables will dictate the sampling design and methods used at each proposed or operational wind-energy facility.

At present, a fundamental gap exists between preconstruction activity of nocturnally active birds and bats and postconstruction fatalities. Given this knowledge gap, quantitative studies on both the presence and activity of nocturnally active bird and bats are needed, including estimates of population size and variation, to provide the best scientific information available to confidently inform decision-makers and other stakeholders concerning risks posed by wind-energy facilities. Rigorous assessments of fatalities reported during the postconstruction periods are needed that incorporate corrections for both searcher efficiency and scavenging biases so that reliable estimates of cumulative impacts can be made. Pre- and postconstruction monitoring protocols are needed that consider both natural variation in population size and seasonal and nightly activity levels. Without a clear understanding of this natural variation, reliable interpretation of risks and actual effects of wind turbine facilities to nocturnally active bird and bat populations will remain elusive.

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# APPENDIX B – RISK FRAMEWORK



## LIST OF TABLES



## LIST OF FIGURES

# INTRODUCTION

A framework for pre-construction prediction and post-construction estimation of impact from wind energy development is presented in this appendix. The framework is loosely based on frameworks developed in other major environmental programs with mandates to assess the degree and magnitude of impacts to wildlife. In particular, portions of the framework are based on existing risk assessment frameworks developed and used by the United States Environmental Protection Agency (USEPA), including the Superfund program. The framework provides a structure for focusing scientific principles and critical thinking toward the goal of effective environmental management, and integrating the views of diverse scientists, regulators, and public participants. The framework also may be used as a decision tool to support regulatory decision making related to the Endangered Species Act (ESA), National Environmental Policy Act (NEPA), and other guidance enacted to protect wildlife.

The framework is based on a growing body of wildlife assessment literature that promotes the concepts of risk assessment for integrated decision-making (see Auswind 2005; Kerlinger 2004; Podolsky 2004; Suter et al. 2003; Urban and Cook 1986; USEPA 1997, 1998; USFWS 2003, 2004). The framework uses the basic concepts of risk-based decisions currently used in major environmental programs, but adapts the successful tools of these programs for use in explicitly addressing issues associated with the effects on wildlife and habitat - particularly birds and bats – from the development and operation of wind energy facilities. The framework is loosely organized around the various steps that the wind industry goes through when developing a wind energy facility.

While this risk framework deals with wildlife risk, wind energy developers must consider a multitude of issues, including abundant, reliable wind, an energy market, access to the wind, and transmission availability. Once these initial issues are addressed, project proponents begin to look at the potential permitting issues they will face.  One of these permitting issues is the potential effects the facility may have on wildlife and their habitat. Clearly potential impacts on wildlife are an important consideration when making the decision to pursue a project (see American Wind Energy Association [AWEA] 2008).

As practiced, risk assessment frameworks have some common characteristics which are utilized in the current proposed framework, and are discussed below.

Vocabulary. The vocabulary of ecological risk assessment is technically complex and often confusing to the public; consequently, we limited the risk vocabulary as much as possible. The component parts of a risk assessment, and the flow of information from one component to another, vary within the many available risk frameworks used by agencies worldwide. However, there is a vocabulary common to many of these frameworks. Table 1 provides definitions for some of the most commonly used terms in the vocabulary of ecological risk assessments. Many of these terms are associated with specific components (or stages) of a risk assessment, for example, problem formulation, effects assessment, exposure assessment, risk characterization, and risk management. The common vocabulary facilitates discussions among individuals with different backgrounds and viewpoints. The vocabulary also supports the consistency of assessment strategies, and facilitates comparisons of results among multiple studies.

**Table 1. Vocabulary of ecological risk assessment.**

| Term | Definition |
|---|---|
| Analysis plan | Final phase of problem formulation in which hypotheses are evaluated to determine how they will be assessed using available and new field data. |
| Assessment endpoint | Explicit expressions of environmental values that are to be protected and that are the subject of the risk assessment. |
| Assessment endpoint entity | Individual, population, or community that is the subject of the assessment. |
| Assessment goal | Purpose related to type of risk assessment (e.g., comparative, retrospective, incremental, etc.). |
| Conceptual model | Diagram that describes key relationships between a stressor and assessment endpoint or between several stressors and assessment endpoints. |
| Ecological risk assessment | Process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors. |
| Effects, characterization of | Definition of exposure-response relationships that are related to assessment endpoints. |
| Exposure, characterization of | Description of potential or actual contact or co-occurrence of stressors with wildlife or other assessment endpoint entities. |
| Framework | Used in this report to indicate a structured conceptual model for risk assessment. Details of the framework, including the components and tiered structure, differ among applications and regulatory agencies. |
| Level of effect | Decrement in an assessment endpoint that is specified as significant to risk managers (e.g., 10% reduction in local abundance). |
| Measure of exposure | Measurement or model result that describes exposure. |
| Measure of effect | Measurement or model result that describes effects. |
| Method | Used in this report to indicate a procedure for conducting a specific laboratory or field study, test or technique, typically resulting in measures of exposure or effect. |
| Probabilistic endpoint | Assessment endpoint that is described in terms of probability (e.g., a bird flying through the rotor swept area has once chance in one thousand [probability = 0.001] of colliding with a turbine blade). |
| Problem formulation | Planning process to define the nature of the problem to be solved and specifying the risk assessment needed to solve the problem. |
| Risk characterization | Integration of site-specific estimates of exposure with site-specific or generic exposure-response models, often using a weight-of-evidence approach. |
| Risk management | The process of deciding whether an action involving risk should proceed, whether mitigation actions should occur, or other relevant actions supporting the decision should occur. |
| Spatial extent | Geographical boundary of risk assessment. |
| Stressor | Agent that causes adverse effects (usually a physical agent in the context of wind energy facility assessments). |
| Susceptibility | Criterion used to select assessment endpoints that are determined based on a high level of exposure, a high level of sensitivity, or both. |
| Temporal extent | Time interval boundary of the risk assessment. |
| Tier (of assessment) | Risk assessment at a specified level of detail, often conducted as part of an increasingly rigorous series of steps. |
| Tiered assessment process | Risk assessment process beginning with few or simple elements and proceeding to additional, more complex elements. |
| Weight of evidence | Methodology for risk characterization if multiple estimates of exposure or effect are measured or estimated using different methodologies. |

Tiered Risk Frameworks: Most risk frameworks have some form of a multi-step process, with the steps frequently referred to as tiers. Tiered assessments are "preplanned and prescribed sets of risk assessments of progressive data and resource intensity. In each tier the assessor will either make a management decision, often based on decision criteria, or continue to the next level of effort" (USEPA 1998). In other words, the risk framework is designed to make risk-based decisions as early in the risk assessment process as the information will allow. In practice, analyses conducted at a lower tier (i.e., a preliminary or early tier) require less information to reach a risk-based decision than those conducted at a higher tier. We have expanded the general concepts available in the literature to reflect the issues that arise in assessing wildlife risk during pre-construction and post-construction activities at wind energy facilities. Such issues include steps to develop a plan to avoid or minimize impacts, decisions to modify or expand the wind facility, and other management actions. In addition, the concept of a "tiered" risk assessment has been expanded beyond the definition used by many regulatory agencies. In the risk framework presented in this document, the tier concept has been expanded to reflect not only level of detailed associated with the risk analysis, but also the decision-analysis steps and associated workflow typically encountered within the context of the risk analysis.

Stakeholder Involvement: Most agencies have developed risk-based decision frameworks that encourage the involvement of multiple stakeholders, including agency staff, industry, and the public. The involvement often includes a review of the applicability and relevance of existing data, the need for additional data collection, evaluation of the level of uncertainty in the analysis, and review of initial risk characterizations. These stages provide a structured flow of information and allow the stakeholders to review and comment on critical aspects of the risk assessment as the analysis proceeds. The framework discussed below encourages interactions with stakeholders as early as practicable in the development process.

Stages of the Risk Assessment. The typical stages of an ecological risk assessment are: 1) problem formulation, 2) characterization of exposure, 3) characterization of effects, and 4) risk characterization. These analysis steps are consistent with those described for human toxicological risk assessment in two National Research Council (NRC) publications: *Risk Assessment in the Federal Government: Managing the Process* (NRC 1983); and *Science and Judgment in Risk Assessment* (NRC 1994). Brief descriptions of the most common stages of risk assessment used in the wildlife framework are discussed below:

> The *problem formulation* stage is a planning process that occurs in each tier of an assessment and is intended to ensure that the risk assessment is defensible and useful and that the scope is workable. In the context of a specific activity such as the construction of a wind energy facility, the problem formulation includes the development of a conceptual model of the potential interaction of birds and bats with the facility, the selection of exposure and effects measurements, and definition of the spatial and temporal extent of the analysis (see Table 1 for terminology definitions). The problem formulation stage is also the point at which the objectives for the tier are determined, and the level of certainty that is required to make decisions within that tier is established. For example, the primary objective for an initial wildlife assessment might be to evaluate several potential locations for a wind project and, based on this evaluation and other information, select one or more locations for further consideration, while the objective of a subsequent tier assessment might be to determine the risk associated with one or more specific sites. Nevertheless, the same metrics for exposure and effects may be

used in both tiers, although the former will often be more subjective and less quantitative than the latter.

The *exposure assessment stage* is the estimation of the expected intensity, time, and extent of co-occurrence or contact of wildlife with turbines, noise, habitat removal, or other stressors (i.e., other causes of environmental impact). Broadly, exposure estimation methods may include a description of the activity (where that provides sufficient information about exposure), direct measurements of exposure, empirical models of exposure, and mechanistic models of exposure. For example, an exposure assessment for birds might consider the amount time birds spend within the zone of risk (rotor-swept area). The exposure assessment may be based exclusively on existing information common with lower tiers or may involve the development of new information (models) and data (field studies) typical of higher tier assessments.

The *effects assessment stage* is the characterization of the exposure-response relationship (e.g., avian fatalities per megawatt [MW] per year, or habitat units affected per MW per year). For wind energy, in early tiers predictions of injury rate or habitat impacts are developed based on historical data from other wind facilities and appropriate models to predict effects for planned or proposed projects. Effects assessments are the most data-intensive pre-construction efforts associated with wind energy development. These effects assessments may address individual risk, such as the number of expected fatalities (typically a regulatory requirement), or population-level responses, such as a potential change in *lambda*, the finite rate of population growth, and/or cumulative effects from this and other existing or reasonably foreseeable future projects. Direct measures of bird and bat mortality or injury can be made after a facility is constructed and in operation (i.e., post-construction) to validate these predictions.

The *risk characterization* stage is the integration of exposure and effects information, expressed in a statement of risk. For example, there is a 1 in 100 chance that an individual bird flying within the rotor swept area will collide with a turbine blade. If the probability of impact is assumed to be consistent for all birds flying through the rotor swept area, then the total number of birds affected is the total number of birds at risk times the probability of impact. Also included in the risk characterization is an analysis (qualitative or quantitative) of the uncertainty inherent in the risk estimates. For some wind sites, lower tiered risk characterizations that are qualitative evaluations of the potential for risk with little actual site-specific field data may be adequate for permitting and development, while at other sites higher tiered assessments with quantitative descriptions of the risk supported by site-specific measurements and monitoring, including a quantitative uncertainty analysis, may be required. Because there are relatively few methods available for direct estimation of risk, a weight-of-evidence approach is often used (Appendix C).

The key issue addressed in the framework is the selection of specific measures of exposure and effects to assess the risk to birds and bats at wind energy projects, as this will determine the necessary methods and metrics. Criteria that are often used to select methods and metrics include the following: policy goals and societal values, appropriate spatial scale, and practical considerations, such as regulatory requirements, time and budget (see Appendix C). State and federal regulations often will determine, for example, whether individual animals (e.g., endangered bats) or populations (e.g., non-listed grassland bird populations) are the focus of the assessment. Ecological endpoints that are considered for policy-based or societal value-based assessment endpoints include: endangered, threatened, or rare species; species with special legal protection; rare community or ecosystem types; protected ecosystem types (e.g., wetlands and streams); species with recreational or commercial value; or species with particular aesthetic or cultural value (Suter et al. 2000). For example, the Australian Wind Energy Association includes “avoidance of wind farms” by birds as one of its two primary endpoint properties (along with direct mortality) (Auswind 2005). Avoidance in this case is measured as changes in usage over a specified geographical area, where avoidance is assumed to have the potential to affect population abundance or individual growth or survival, and should be an issue of discussion early in the assessment. The term avoidance suggests an individual behavioral response that is often difficult to measure.

As an alternative to avoidance, some existing risk assessments of wind energy facilities have evaluated changes in population density at distances from turbines rather than “avoidance” per se (Buffalo Ridge report, Leddy et al. 1999). Avoidance can be evaluated at multiple scales. For example, it could be local area (Leddy et al. 1999) or wind resource area wide (Johnson et al. 2000a). Large-scale avoidance may also result in fragmentation of habitat for some species. Avoidance may (and by definition habitat fragmentation does) reduce individual or species fitness as a result of reduced access to food, cover, potential mates, or other components of habitat – which theoretically could be measured as a decline in reproduction, survival, or genetic diversity. However, this connection between avoidance and population demographics has not been well established (NRC 2007), and is an important area for future research.

Some advantages of using the framework described in this appendix to assess risk to wildlife from different wind power projects include the following:

1. Encourages consistency among ecological assessments by providing a structured framework and common language.
2. Encourages methodical selection of well-defined, susceptible, valued wildlife species, appropriate properties of those species, and critical levels of effects that are the subject of the assessment.
3. Provides a framework within which the amount and type of data needed to support environmental decisions can be discussed, resolved, and implemented.
4. Provides a structured flow of information that encourages input from all stakeholders.
5. Encourages good science, including well thought-out assessment designs, appropriate endpoint selection, and evaluation of uncertainty.
6. Focuses the assessment on the environmental decisions of greatest relevance and importance and the level of certainty required to make those decisions.
7. Encourages the development of a knowledge base that can be used in many types of assessments.

## FRAMEWORK DESCRIPTION

Figure 1 presents a graphical presentation of the general framework for minimizing impacts of wind development on wildlife in the context of the siting and development of wind energy sites. In the framework, risk tiers are associated with specific activities in the pre- and post-construction stages of a wind development project, and reflect the amount and types of information required for decision-making within a specific tier. For example, suppose that in the early stages of development a company identifies several sites that are available and meet the criteria for construction of a wind energy facility and the company is interested in comparing the risk to raptor survival at each site. A lower tiered assessment (e.g., a first tier), which can be accomplished in a small amount of time on a limited budget, could be used to compare the sites. While this type of assessment will have a relatively low cost and may be adequate to identify screening criteria on the landscape scale, the relative uncertainty of this approach is high because it comprises a review only of existing information. A higher-tiered assessment (e.g., a second tier), consisting of a site visit, and even a longer-term (e.g., third tier) field study coupled with extensive modeling of potential impacts will have less uncertainty, but will take longer and be more costly. The need for, and usefulness of, any specific tier is established by the feedback loop built into the framework described in this appendix. As the information for each tier is processed, the need for additional studies to support the risk-based decisions is explicitly addressed. In general, the need to advance to a higher tier is based on whether there is adequate information to estimate risk (within an acceptable bounds of uncertainty), and whether the information is sufficient to support management decisions that are based on the magnitude of the risk estimate.

We illustrate the application of this framework by using a generalized framework consisting of five tiers. Tiers 1 – 3 are generally associated with pre-construction assessments, and Tiers 4 and 5 are generally associated with post-construction assessments; although, depending on the study design, Tier 5 studies may begin pre-construction. Note that within each tier, information is obtained and decisions are made concerning the quality and quantity of the required information. If required to more fully address the questions of interest, additional data are obtained. A brief description of each tier is provided below. Additional information on the methods and metrics utilized in each tier, and the basis for interpretation and risk-based decision-making within each tier, are described in the body of the resource document, *Comprehensive Guide to the Study of Wind Energy/Wildlife Interactions*.

Using the framework, a hypothetical case study is presented, involving a wind project in central California. The company (called Company X) has identified a potential market for renewable energy and has looked at wind resources, transmission, access, and other non-wildlife related issues and has developed a list of four potential project areas. The case study is not meant to represent any specific project. The case study addresses a range of issues that are beyond the scope of a typical wind development project. The objective of the case study is to illustrate the application of a large number of methods and metrics that are discussed in detail in the resource document. References to individual metrics and methods within each tier are provided as appropriate.

**Preliminary Site Screening and General Area or Regional Assessment**

The objective of preliminary site screening (preliminary screening) is to assess conservatively the suitability of a potential wind energy site(s) during the pre-construction phase. This preliminary screening might occur at a landscape scale, covering a general area or even a region, or it might be restricted to looking at one or more areas already identified as potential project sites. Regardless, the goal is to identify with existing information the potential wildlife conflicts associated with developing wind energy in the region, area, or specific sites. This information can then be used to aid in selecting one or more potential sites that can be carried through to the next level of evaluation. Where available information is adequate, the developer should focus on sites expected to have minimal risk to wildlife, or identify sites where, if development occurs, there is a high potential for impact mitigation.

# Key Components of A Risk Analysis

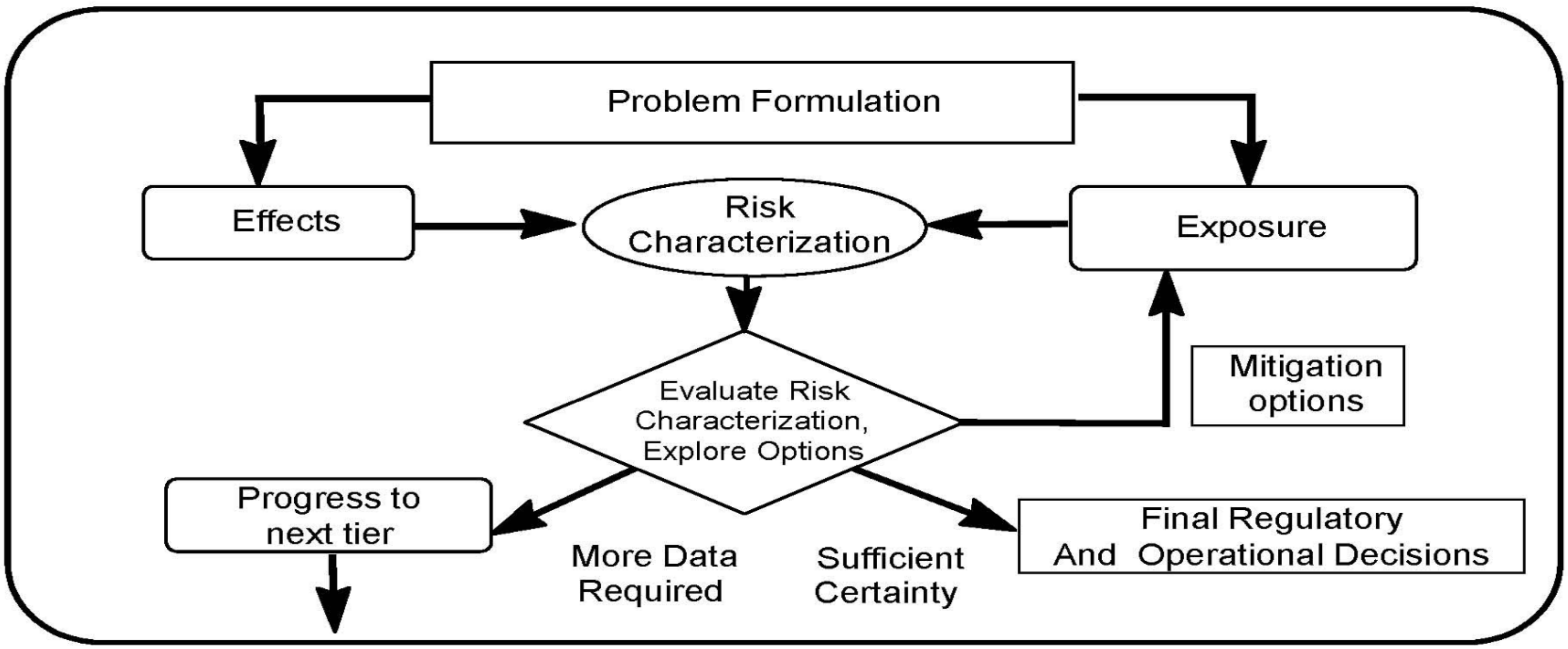


**Figure 1. Basic concepts employed in the risk framework.**

This preliminary screening typically will identify where information gaps exist. The screening process typically will not include stakeholder involvement, but wind developers are encouraged to engage regulatory agencies and other stakeholders as early as possible in the initial discussions and investigations associated with wind energy siting decisions, as stakeholders may be a source of available information used in the screening. Some wind developments will not require the preliminary screening process, particularly those in which advanced planning and prior siting decisions have been completed or when an existing facility is being expanded.

A key step in any tier is the development of a problem formulation. Normally, problem formulation for the screening process will be preliminary, and the more detailed problem formulation will occur as a part of later tiers. Regardless of whether it is during screening or the assessment of a specific site or sites, because this is the first phase of the formal analysis, and the first time the problem will be formulated within a multi-tiered process, this initial problem formulation could influence the methods, metrics, and data collected in subsequent tiers. As part of problem formulation, the potential types and causes of impacts to wildlife are typically identified and selected. The objective of problem formulation is to focus the risk analysis on the most relevant potential geographic and biological factors affecting wildlife risk. In most cases, the wildlife species, guilds, and communities of interest (and their properties), including those that are expected to affect a management decision, are identified during this step. For example, passerines make up the majority of fatalities associated with wind energy projects and comprise the largest proportion of birds passing over most wind energy facilities (NRC 2007). Nevertheless, raptors in general appear to be more susceptible to collisions than other groups of birds, probably because of their foraging and flight behavior. Therefore, during the problem formulation stage of a proposed facility in a location where raptors are common, methods and metrics focusing on measuring risk to raptors would be appropriate (Hoover and Morrison 2005).

The selection of species of interest must consider not only presence and exposure, but also geographic characteristics of the facility and species-specific characteristics that influence behavior. For example, at the Foote Creek Rim wind facility in Wyoming (Johnson et al. 2000b), the raptors and other large bird species most exposed to turbines were golden eagle, American crow (*Corvus brachyrhynchos*), red-tailed hawk (*Buteo jamaicensis*), common raven (*Corvus corax*), and black-billed magpie (*Pica pica*). The common raven and red-tailed hawk had similar exposure based on flight height and abundance, but fatality monitoring showed that the latter species is much more susceptible to collisions with wind turbines, apparently because of hunting behavior (NRC 2007).

In any case, the problem formulation stage, even informally within screening, must consider the species of interest and the associated turbine-related causes of risk. In the more formal problem formulation process, a conceptual model of the potential wind energy-wildlife interactions is developed, and the methods and metrics used to assess the magnitude of risk are initially selected. The required data at this stage typically are general rather than site-specific in nature, and are publically available and easily accessible. A feedback loop is built into the decision logic, allowing for the re-evaluation and selection of sites during this preliminary screening phase of the assessment.

*Case Study Example*

To illustrate this screening process we begin our hypothetical case study with four potential sites in a general area (see Chapter 2 for specific methods and metrics for identifying candidate sites). For each site, preliminary information appropriate for a Tier 1 site screening was compiled. The objective of compiling this information is to forecast potential exposure to birds and bats at the individual and population level at each of the candidate wind facilities.

Information sources included the state wildlife agency's wildlife database, which includes biological information on the status of declining or vulnerable species. In addition, we also used information from the state wildlife and habitat atlas (WHA) system, containing life history, geographic range, habitat relationships, and management information for regularly occurring species of amphibians, reptiles, birds, and mammals.

The desktop evaluation of the four candidate sites revealed that two of the sites were near known high-use areas of two species of concern that are known to collide with wind turbines. These candidate sites were eliminated from further consideration by the wind developer. In addition, the transmission capacity of the candidate sites was deemed insufficient for development from a cost-effective perspective. The remaining two candidate sites were further evaluated during the Tier 2, the site evaluation and selection portion of the assessment.

**Site Evaluation**

A more in-depth assessment of the candidate sites selected through the screening process is conducted during site evaluation, with the goal of site selection. Within each tier, the process begins with the problem formulation stage. Generally, if a formal screening process occurs, the problem formulation generated during screening can be used as a guide for problem formulation in site evaluation and selection. More site-specific questions of interest should be explicitly noted, however, and the problem formulation will necessarily be much more detailed. For example, the list of species of concern may contract or expand even though the geographic characteristics of interest and impacts of concern generally will not change. A review of the problem formulation at each tier of the assessment is strongly encouraged. The exercise should help reinforce the objectives of the study, and focus the methods, metrics, and data requirements.

At this step in the process it is essential that a review of the available data has been completed, either during screening or site evaluation, to assess the quantity and quality of the information with respect to the questions of interest. Site screening and evaluation depend on publically available and easily accessible data; however, the data requirements are generally site-specific for site evaluation and selection and normally include a site visit and empirical observations of site characteristics. An active analysis of the data is generally required to forecast the relative risk posed by site development to wildlife populations. If the data are sufficient, the final site(s) is (are) identified and the more quantitative baseline and modeling studies are implemented, if necessary. In some instances, the permitting process would begin at this point without the need for further studies.

*Case Study (continued)*
Because of the regulatory environment in the state where the two sites are located, Company X began the permitting process early by approaching the county agency responsible for issuing a land use permit. Company X and the county representatives met to review the county's standard conditions for addressing resource policies that apply to wildlife issues. Working closely with the county, the following key objectives, including key issues of concern, were developed during the problem formulation:

- The overall objective of the site evaluation is to site the proposed wind facility at a location that will minimize impacts to wildlife during post-construction operation of the wind facility, or where the identified risk and potential impacts can be mitigated.
- Habitat impacts during pre-construction were discussed and potential habitat impacts for bird species were identified as a concern for site selection. In addition, general habitat loss caused by construction, and changes to the biological community structure and function (such as aversion/displacement due to the presence of wind turbines) were identified as potential issues of concern.
- Special consideration in site selection is attributed to potential risk of turbine operation on state-listed Threatened or Endangered species. In the state where this case study is set, potential risk associated with these species may require an additional permit under the State endangered species act. If the affected species are also federally listed, the facilities may also require permits under the Federal ESA.

After reviewing the initial problem statements and initial available information, Company X decided that additional details and biological data were required for a final site selection. The two sites selected for evaluation were similar in every respect (e.g., wind, transmission, access) with the exception that the geographical locations of candidate sites (called site 1 and site 2) were dissimilar. Candidate site 1 was located in desert regions at high elevation, and candidate site 2 was located in grasslands at a lower elevation.

Company X received landowner permission to access the remaining candidate wind energy sites, and arranged for a wildlife biologist knowledgeable about the biology of wildlife species of interest in the region to conduct a reconnaissance survey of the sites. Company X personnel and their consultants made site visits for the purpose of siting possible turbine locations. The biologist prepared a more detailed survey by securing recent, publically available aerial photography of the site. The survey provided coverage of all land cover types in and immediately adjacent to the potential project sites that provided a basis for predictions about species occurrence at the site throughout the year.

Data and pre-permitting and operational studies from nearby wind energy facilities were obtained and evaluated (see Chapter 2 for a discussion of methods and metrics appropriate for use in site evaluation). A comparable wind facility site near site 1 was identified and the geographical characteristics, the wildlife species, the wind conditions, and the geography were all determined to be similar to site 1. While not always available, the preliminary development plan, including potential turbine types and turbine arrangements for site 1 was also similar to the existing wind facility. Therefore, the nearby site could provide insights into the expected fatality rate at the candidate site 1 location. Evaluation of post-construction monitoring studies at the nearby-site showed relatively high turbine-caused raptor mortality associated with spring and fall migration. After extensive analysis (see Chapter 2), the developer determined that the information and insights gained from the nearby site could reasonably be used to forecast expected wildlife impacts at site 1.

Evaluation of existing data collected at an existing wind facility near site 2 showed little avian mortality and no bat mortality associated with site operations. However, the available data set represented only one full year of operational monitoring. Therefore, the ability of the nearby site to represent the expected fatality rate at site 2 was uncertain. The developer determined that additional information needed to be collected at the site 2 location to better assess the risk to bird and bat individuals and populations at site 2.

Site 2 was selected for further evaluation based upon the review of existing site-specific data, review of post-construction data at the near-by site, and expert judgment. Although the nearby-site information suggested negligible risk resulting from wind energy operations at site 2, there was uncertainty over the amount of use by both birds and bats at the proposed site, and how this uncertainty should translate into expected avian and bat risk. Nevertheless, Company X decided move to the project design and permitting step of the assessment framework.

**Project Design and Permitting Process**

As with the prior steps in the risk assessment, the project design and permitting phase begins with a re-evaluation of the problem formulation. Information gained during the site-specific evaluation analyses can be reviewed and used to update or modify the questions and issues of interest. Again, investigators need to make a decision concerning the quality and quantity of existing information. If the information collected in prior steps in the process is sufficient, the formal permitting process is implemented. However, if an active analysis of existing data results in the need for additional information, more quantitative baseline and model studies are designed and implemented.

The objective of the baseline studies is to forecast the quantitative risk and potential impacts to birds and bats at the selected site(s). The studies may utilize models or statistical analysis of existing data and often include field studies to fill important data gaps. The fatality predictions, and in some cases habitat risk/impact predictions, should be made in such a way that it is possible to evaluate them post-construction. If necessary, this is the point in the framework when the pre-construction component of studies requiring both pre- and post-construction data (e.g., before-after control-impact [BACI] study) must be initiated (see Chapter 5 for further information). Note that before-after studies, if appropriate, generally will be carried into a post-construction analysis (see below) during post-construction monitoring.

During the project design and permitting process, a review of available pre-permitting data to evaluate which species might collide with turbines or suffer direct and indirect habitat impacts and which non-biological factors (such as topographic and facility design features) might contribute to this risk is essential. The presence of special-status species using areas that put them at risk may be enough to determine that there are potential impacts. Turbine design characteristics and proposed siting locations are two known factors that should be considered during the impacts analysis in assessing potential contribution to risk. Some factors are presented with the understanding that little is currently known about their contribution to fatality or displacement risks, so it is incumbent upon biologists making impact determinations to be familiar with the latest research. Operations monitoring from neighboring projects can provide important information on potential impacts. Information developed during Project design and permitting studies should support the preparation of a plan to avoid, minimize, or mitigate the expected wildlife risks.

During the permitting process, additional information generated during site field studies may be required. Frequently, companies will choose to collect site-specific data to assist in the design of a facility even when not required by the permitting process. Information is collected until sufficient data are obtained, so that the company, regulators and stakeholders understand the risk potential of the planned wind energy site. An objective of this feedback loop is to work closely with regulators and other stakeholders to obtain a high degree of belief that the wind energy project will have minimal, or at least acceptable, wildlife impacts.

At the end of the project design and permitting process, if the anticipated risks to wildlife are determined to be acceptable by the developer and the regulatory authority when a permit is required, the project is constructed and the post-construction stages of the project are initiated.

*Case Study (continued)*
Using the existing information collected in the evaluation stage, Company X decided that while existing fatality studies suggest that exposure of bat populations in the geographic area of site 2 is minimal, there remains a great deal of uncertainty regarding risk to bats. Therefore, at the project design and permitting stage of the assessment problem formulation addresses exposure of bat species to turbines, with an emphasis on exposure of Threatened and Endangered species. The developer also determined that more information was required to forecast site-specific risk to avian species.

Methods and metrics appropriate for forecasting avian and bat risk were reviewed (see Chapter 3), and the developer determined that one year of pre-construction diurnal avian surveys, including nocturnal radar monitoring studies, and bat use surveys during the spring and fall migration season were needed to accurately address the fatality potential of birds and bats under conditions at site 2. The county permitting authority and Company X agreed that the additional information was needed and Company X implemented a series of studies designed to meet the additional data needs.

The studies were designed to collect information on avian flight direction, migration phenology, migration intensity (movement rates), and flight altitude of migration during each season, and bat use and species composition using methods described in Chapter 3. The site was a mixture of native shrub-steppe vegetation and areas that had largely been converted to cultivated wheat fields interspersed with grasslands. Therefore, with consultation of the County Planning Department, raptor use counts, songbird use counts, and nocturnal radar studies and bat acoustic surveys were implemented. The objective of the studies was to gather information for estimating the number of bird and bat collisions as a function of behavior, flight patterns and seasonal distribution and abundance.

In addition to the above studies, a baseline fatality study was implemented. The objective of the site-specific fatality study was to provide baseline information on the fatality of avian species that will later be compared to data collected during post-construction fatality studies, as a part of a before-after (BA) study design (see Appendix A). The Company reviewed the many types of survey designs that are appropriate for this objective (see Chapter 3). The Company presented a proposed protocol for studies to the county. Based on these discussions the company chose to use matched pairs of study sites in both the development area and a control area, in the context of a BACI study design (see Appendix C). Details of this approach and recommended implementation strategies are found in Chapter 3.

At the conclusion of the first year of site-specific monitoring, and analysis of the first-year data was carried out. Population models based on the abundance studies were developed. Flight patterns were evaluated with respect to the expected collision rate anticipated with the proposed turbines. Analysis of the data resulted in the conclusion that individual birds representing several avian species were at risk, including the golden-crowned kinglet (*Regulus satrapa*) and red-tailed hawk. The pre-construction fatality studies identified several fatalities for these species within the site boundaries. The golden-crowned kinglet is a low-flying nocturnal migrating neo-tropical songbird that was considered to have a potential exposure to collision with wind turbine blades during migration. However, the risk to individuals of this species was estimated to be low, with no population effects indicated. The red-tailed hawk, on the other hand, resides in the area year-round and its hunting behavior is thought to create a potentially high risk of collision. Nevertheless, the number of fatalities estimated as likely to occur was unlikely to result in a measurable impact on the local population. Bat use was determined to be low throughout the area, although some use by the hoary bat (*Lasiurus cinereus*), a species known to collide with wind turbines, was discovered during the fall migration season. In addition, no impacts associated with habitat disturbance were anticipated, including changes in bird or bat behavior caused by the presence of the wind turbines. Evaluation of the site geographic characteristics and food sources indicated that risk to burrowing owl (*Athene cunicularia*) habitat was negligible.

However, in an attempt to minimize any unanticipated risk, Company X initiated a mitigation planning process with the goal of minimizing any unexpected impacts that could occur during post-construction operations. The planning was focused on siting turbines to minimize risk to birds and bats based on the baseline data. While there is a great deal of uncertainty regarding the effectiveness of many risk reduction measures, Company X decided to test the hypothesis that painting turbine blades would decrease the number of red-tailed hawk fatalities. The company randomly selected turbines for blade painting (the treatment) and a matched pair of turbines painted using the standard paint adopted for the facility (the control). In addition, Company X also considered the implementation of a cooperative grazing program with the landowner to improve offsite habitat for the burrowing owl.

A construction permit was granted by the County Planning Department containing specific provisions for two years of post-construction monitoring. Therefore, the project moved into the post-construction assessment phase of the analysis.

**Site Build-Out, Operation, and Post-Construction Evaluation**

Prior to the initiation of studies during construction and post-construction activities, problem formulation is reviewed and information gathered during prior tiers is used to revise, as necessary, the issues and endpoints of concern. As with prior tiers, an evaluation of existing information is conducted to determine the focus of post-construction monitoring, which then is undertaken. Additional data may be required during any stage of the assessment process, and the framework should incorporate a feedback loop in which additional data can be collected. Note that some studies begun during pre-construction may continue during the post-construction phases.

Chapters 4 and 5 describe the standardized techniques recommended for collecting, interpreting, and reporting post-construction monitoring data. Typically, the objective of post-construction operations monitoring at wind turbine sites is to collect bird and bat fatality data, and compare the results to similar data collected from other wind energy facilities. In some cases post-construction monitoring data also can be compared to data collected during the pre-construction phases of the project. This information is required to evaluate and verify the effectiveness of avoidance and minimization measures and, when a permit is required, to document compliance with applicable permit requirements. In addition, special post-construction studies may be needed to evaluate the success of mitigation and risk reduction strategies.

At a minimum, the primary objectives for post-construction operations monitoring are to determine:

- Whether estimated fatality rates described in pre-permitting assessment were reasonably accurate;
- Whether habitat impacts described in pre-permitting assessment were reasonably accurate;
- Whether the avoidance/displacement, minimization, and mitigation measures implemented for the project were adequate or whether additional corrective action or compensatory mitigation is warranted; and
- Whether overall risk to wildlife is acceptable.

Both direct and indirect impacts may be addressed in post-construction studies. Direct impacts refer to bird and bat collisions with wind turbine blades, meteorological towers, and guy wires, and destruction of habitat. Direct impacts are determined by site-specific surveys of wildlife fatalities and through the measurement of habitats permanently lost. Operations monitoring of fatality impacts typically consists of counts of bird and bat carcasses in the vicinity of wind turbines and may include ongoing bird use data collection. The number of carcasses counted during operations monitoring is likely to be an underestimate of the birds and bats actually killed by wind turbines for several reasons. Searchers will inevitably miss some of the carcasses. In addition, some carcasses may disappear due to scavenging or be destroyed by farming activities such as plowing. Some birds and bats also may not be counted because injured animals may leave the search area before dying. Most fatality estimates reported at wind energy projects are therefore extrapolations of the number of fatalities with corrections for sampling biases (see Chapter 3). Some bird and bat fatalities discovered during searches and used in fatality rate estimation may not be related to wind turbine impacts. It is common for studies of fatalities at wind energy facilities to assume all fatalities discovered on study plots under turbines are due to turbine collision, unless an alternative cause of death is obvious (NRC 2007). Natural bird and bat fatalities and predation occur in the absence of wind turbines, and unless background fatality is included in an operations monitoring study, the results may incorrectly estimate project-related fatality rates. If background fatality studies are conducted during pre-construction studies this potential bias in fatality estimates could be taken into account. Background fatality survey methods should be consistent with carcass survey methods used at the turbines. In most cases it is not necessary to conduct background fatality surveys unless greater precision in wind project fatality estimates are needed. The alternative is to make the conservative assumption that all fatalities found in post construction studies are attributable to the wind facility.

While the estimation of direct habitat loss is fairly straightforward and is determined from the actual footprint of the wind facility (e.g., turbine pads, roads, and power substations), indirect impacts from behavioral avoidance of a wind facility is more difficult to measure and may be a major concern at some facilities. These impacts require a measure of animal behavior in response to the presence of wind facilities. The impact occurs as a result of an animal's reduced use of otherwise suitable habitat because of the presence of structures or human activity associated with the structures in a facility. These impacts may be short-term, if animals habituate to the facility, or long-term, if no habituation occurs.

Methods for conducting these fatality field surveys are discussed in Chapter 4. Equations for estimating the "true" fatality rate, including methods for adjusting the found number of birds and bats for observer bias and scavenging, are also discussed in Chapter 4. Habitat impact assessments are discussed in Chapter 5.

Population models (see Chapter 5) can be used in post-construction studies to assess the risk to wildlife populations. Population models are generally restricted to species that have been shown to be of high concern in prior tiers of the assessment. Combining model predictions with use surveys can provide insights into the risk at the population level as a function of the fatality rate associated with individuals, and can provide insight into the likelihood that habitat loss is having a population level effect.

Adaptive management, albeit primarily passive adaptive management (Walters and Holling 1990), may be implemented at some wind energy facilities to evaluate the success of post-construction mitigation measures. The decision to expand or modify a wind facility can be made at any time during the operation of a wind facility. Decisions are made as new insights are drawn from the database of site-specific data. For example, the initial mitigation approaches proposed in pre-construction tiers may not result in the anticipated level of risk. Alternative management strategies can be implemented, new data collected and analyzed, and the risk estimates refined within an overall management strategy. Chapter 5 provides additional information on adaptive management techniques and approaches.

Within the risk paradigm, the uncertainty associated with the direct measurement (or modeling) of wildlife impacts should include explicit statements of the uncertainty in the risk characterization. The approach to uncertainty analysis can vary between simple statements of the unknown factors affecting the risk characterization to a formal analysis of uncertainty, using for example Monte Carlo analysis (Manly 1997) to generate a prediction uncertainty from a population model. Uncertainty in fatality estimates should generally be reported, and uncertainty due to inconsistency in survey design changes, small sample sizes, and spatial and temporal variability should be discussed.

Post-construction methods used to estimate impacts and evaluation predictions of risk should be refined relative to those employed in earlier tiers. Site-specific measurements of fatality generally are required. Methods that estimate the probability of an individual kill, habitat loss, or population decline may be appropriate at sites where impacts of the wind facility are expected to be significant. The selection of methods and metrics for probabilistic assessment are discussed in Chapter 5.

The tiered framework ends when the site is reclaimed at the end of the project life.

*Case Study (continued)*
The permit required two years of post-construction monitoring. The BACI paired site fatality survey was continued during the post-construction phase of the project (a Tier 5 study). As part of the operations monitoring, data were gathered on site-specific geographic features (elevation, terrain descriptions, etc.). In addition, explicit operating information from each turbine was compiled during the first year (operating time per search interval and wind velocity during operations, etc.). At the end of the first year, fatality data compiled during the operations period were evaluated, and species-specific fatality estimates per MW-rotor swept hour were derived (see Chapter 4) and compared to the baseline estimates generated during pre-construction studies. The data showed a significant increase (above baseline) in the fatality rates of the red-tailed hawks during migration. The increase was incurred in spite of the mitigation methods in place at the time of initial operation. Fatality rates for other species were not significantly

different than the background estimates generated during pre-construction studies, or were otherwise consistent with the predictions developed using baseline data.

Based on the first-year findings, a study focusing on the red-tailed hawk population demographics was initiated. The study objective was to correlate the red-tailed hawk fatalities with site-specific covariates that may be associated with the fatality increase and to estimate the impact of these fatalities on the viability of the local population. A predictive model, parameterized using site-specific engineering and biological data as model inputs, was created and tested. The model was used to forecast the probability of an individual bird fatality as a function of changes in current operation of the wind facility, and the effect of those changes on the demographics of the population. Using results from the model, and additional information from the literature concerning the success rate of mitigation approaches, a rodent control program was initiated in an attempt to eliminate a key food source of the red-tailed hawk. Operations monitoring continued into the second year of the post-construction phase under the assumption that the data analysis and modeling would be repeated as new data were compiled. A population model (see Chapter 5) was developed specifically for the red-tailed hawk, and was parameterized using region-specific geographic information and species-specific biological information. Results from the population model indicated no population-level risk was associated with wind energy operations.

The above discussion explains in some detail the different potential tiers that could be used in a tiered assessment of the potential risk to wildlife from wind energy development and a discussion of the evaluation of risk predictions and risk reduction measures. While not all facilities will need to conduct all levels of this tiered risk assessment, we included a discussion of all tiers for a complete illustration of the process. The hypothetical case study was used to illustrate the different tiers. As with the description of the tiered process, the case study was carried through a much more complicated process than is typically necessary for a wind facility, again for the purpose of illustrating the process.

### Determining the Appropriate Level of Precision in Site Studies

Studies and analyses performed in a risk assessment must identify the appropriate level of precision and scientific rigor needed before each study can begin. Factors that figure in determining the appropriate level of precision are described in detail in Appendix C and include such items as regulatory requirements, cost, available time, site conditions, and other topics. In the case of state or federally listed species, specific protocols that help to establish the level of precision and scientific rigor required may already be available. In the case of commonly conducted studies needed to address state or federal environmental impact assessments, the appropriate level of precision is often well established. Budget is often the determining factor in the level of effort. It is important to recognize that some questions are unanswerable with available methods. The level of effort also is strongly influenced by the level of confidence desired in answering questions. In most cases, wildlife studies cannot achieve and do not require a high level of precision. Wildlife studies related to wind projects should strive for a level of precision in the studies that is scientifically supportable, but that provides a reasonable balance between cost, time required, and usefulness for future meta-studies.

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# APPENDIX C – STATISTICAL CONSIDERATIONS: STUDY DESIGN AND DATA ANALYSIS

## LIST OF TABLES



## LIST OF FIGURES

## INTRODUCTION

Public interest in the impact of wind energy development on wildlife has led some state and federal agencies responsible for permitting wind facilities or protecting potentially affected wildlife species to require studies to:

- Predict the potential effect of proposed wind facilities on wildlife and their habitat, particularly birds and bats.
- Evaluate the actual effects on wildlife and their habitat from wind facilities in operation.
- Determine the causes of wildlife fatalities and habitat impacts.
- Evaluate methods for reducing risk of fatality and habitat impacts.

This appendix provides a guide to regulators, industry developers, scientists, and interested members of the public on statistical considerations so that studies of wind facilities and wildlife interactions will withstand scientific, legal, and public scrutiny. While wind energy development presents somewhat unique environmental perturbations, the principles involved in designing studies of its effect on wildlife are the same as for other environmental perturbations.

This appendix describes how the quantification of effects fits into the various philosophies of design, conduct, and analysis of field studies. This appendix is an update of the guidelines for design and statistical analysis of impact quantification from Anderson et al. (1999).

In a perfect world, impacts would be measured without error. For example, bird fatalities on the site of a wind facility could simply be counted and the cause of death assigned with certainty. However, when a complete count or census is impossible then impacts must be detected by the use of scientific study and statistics. Two general classes of statistics can be recognized. Descriptive statistics (e.g., mean, median, range) simply describe the parameters of interest. The ultimate objective of inferential statistics, however, is to understand – make inferences about – a population (group of units) from information contained in a sample (Scheaffer et al. 1990). Statistical or inductive inferences are made properly in reference to:

1. The design and protocol by which the studies are conducted in the specific study areas;
2. The specific time period of the study; and,
3. The standard operating procedures (SOPs) by which data are collected and analyzed.

If either the design protocol or the SOP is inadequately documented, then the study is not replicable and its validity is uncertain. In such a situation, it is impossible to know the proper extent of statistical conclusions and there would necessarily be less scientific confidence in the statistical inferences. A common practice in ecological studies is the extension of study conclusions beyond the specific study areas to unstudied areas not included in the original sampling frame. This practice is acceptable and often necessary, albeit risky, as long as the assumptions are specified and it is clear that the extrapolation is based on expert opinion. When the extrapolation is presented as an extension of statistical conclusions it is an improper form of data analysis. *Deductive inferences* that extend beyond the specific study areas to draw general conclusions about cause-and-effect aspects of operating a wind facility may be possible if enough independent studies of different wind facilities identify similar effects. However, *statistical inferences* beyond the study areas are not possible; nor should this be the primary objective of quantification of impact, given the unique aspects of any development. Although a properly designed and implemented study conducted in only one location is valid, as noted above (deductive inferences) it is risky to extrapolate such findings to other locations and times.

### The Traditional Experimental Design Paradigm

The traditional design paradigm for the true experiment is defined in terms of the following principles (Fisher 1966, Pollock 1996):

- ***Control.*** The scientist tries to control (standardize) as many variables as possible except for those associated with the different treatment conditions that are to be compared.
- ***Randomization.*** The scientist randomly allocates treatments to experimental units so that the values of variables not controlled are allocated equally over units (at least on average).
- ***Replication.*** Each treatment is allocated to multiple independent experimental units so that unexplained or inherent variation can be quantified. Information about the amount of inherent variability is needed for valid statistical testing.

Two additional methods are useful for increasing the precision of studies when the number of replicates cannot be increased:

1. Group randomly allocated treatments within homogeneous groups of experimental units (blocking).
2. Use analysis of covariance when analyzing the response to a treatment to consider the added influence of variables having a measurable influence on the dependent variable.

The study of wind energy development impacts is made difficult by the relatively large area potentially affected, the relative scarcity of many of the species of primary concern, and the relative scarcity of the events being measured (e.g. mortality, use of a particular turbine by a particular species). Quantification of the magnitude and duration of impacts from a wind facility necessarily requires an observational design, because the area to receive the wind facility and the areas designated as the references (controls) are not selected by a random procedure (i.e., they are based on wind potential, existing infrastructure and other technical, business and environmental considerations). *Observational studies* also are referred to as “sample surveys” (Kempthorne 1966), “planned surveys” (Cox 1958), and “unplanned experiments / observational studies” (National Research Council [NRC] 1985). See Manly (1992), McKinlay (1975), Morrison et al. (2008), and Manly (2009) for a discussion of the design and analysis of observational studies. *Impact studies* typically are large field studies, as opposed to manipulative experiments or observational studies in subjectively selected small homogenous areas. Data are collected by measurement of an event and the resulting change in selected response variables in time and space.

Conclusions concerning cause-and-effect regarding impacts of wind facilities on wildlife are limited. Practically speaking, pre-treatment data are often unavailable, identical “control” areas seldom exist, and thus proper controls are absent. Moreover, there is no random assignment of treatment, and replication is usually impossible. Wind facility sites are selected because they are very windy, there is access to the sites, a market exists for the power produced, and there is an existing infrastructure (e.g., a power grid). These sites tend to be relatively unique topographically, geographically, and biologically, and are difficult to duplicate, at least in a relatively small area. Even if all the potential wind sites are known in an area, the decision regarding where to locate the facility is never a random process. Finally, the expense of a wind facility makes replication impractical. Thus, one does not have a true experiment.

In all studies of impact, including wind facility impacts, it is essential that several basic study principles be followed. The following is a brief discussion of some of the more important principles. For a detailed discussion of these principles see Green (1979), Skalski and Robson (1992), and Morrison et al. (2008).

*Know the Question*
It is essential that the question being addressed by the study be clearly understood. Study questions form the basis for developing hypotheses, and help to define the parameters for comparing hypothesized outcomes with actual study results. (See section on Data Analysis for a more direct discussion of hypothesis testing.) The design of the study protocol depends on the question being addressed. The protocol that addresses the question of wind facility risk to individual animals is substantially different from a protocol addressing the risk to a population of animals. A clear understanding of the question increases the efficiency of the research. It is a waste of time and money to collect vast quantities of data with the idea that their meaning will become obvious after the data are analyzed. The outcome of a study is more likely to be useful if an appropriate study design is followed and all interested parties have a clear understanding of the research question. Studies of wind facility impacts on wildlife should allow the question to be addressed through inductive (statistical) inferences as well as deductive inferences (expert opinion). These inferences should help provide a sound scientific basis for development of protocols for quantification of wind energy impact.

*Replicate*
*Replication* means repetition of the basic experiment (Krebs 1989) within each time and location of interest, producing multiple sets of independent data. Essential for statistical inference, replication allows the estimation of variance inherent in natural systems and reduces the likelihood that chance events will heavily influence the outcome of studies. Proper statistical inference must also keep the proper experimental unit in mind. In studies of wind energy development the experimental unit may be a turbine, a string of turbines, or the entire wind facility. Using the wrong experimental unit can lead to errors in the identification of the proper sample size and estimates of sample variance. Confidence in the results of studies improves with increased replication; generally speaking, the more replication in field studies the better.

The concept of replication often is confusing in the conduct of environmental studies; what constitutes replication of the basic experiment depends on the objective of the study. For example, if the objective is to compare bird use of a wind facility to bird use in a similar area without the wind facility, replication may be achieved by collecting numerous independent samples of bird use throughout the two areas and all seasons of interest. In this case the sample size for statistical comparison is the number of samples of bird use by area and season. However, if the objective is to estimate the effect of a wind facility – or all wind facilities in general – on bird use, then the above wind facility constitutes a sample size of one, from which no statistical comparisons to other sites are possible. The statistical extrapolation of data from one study site to the universe of wind facilities is one of the more egregious examples of pseudoreplication (i.e., “false” replication) as defined by Hurlbert (1984) and Stewart-Oaten et al. (1986).

When determining the sample size in an experiment, a good rule to follow is that the analysis should be based on only one value from each sample unit. If five sample plots are randomly located in a study area, then statistical inferences *to the area* should be based on five values – regardless of the number of animals which may be present and measured or counted in each plot. If five animals are captured and radio-tagged, then statistical inferences to the population of animals should be based on a sample of five values, regardless of the number of times each animal is relocated. Repeated observations of animals within a plot or repeated locations of the same radio-tagged animal are said to be dependent for purpose of extrapolation to the entire study area. Incorrect identification of data from sampling units is a common form of pseudoreplication that can give rise to incorrect statistical precision of estimated impact. It becomes obvious that replication is difficult and costly in environmental studies, particularly when the treatment is something as unique as a wind facility.

*Randomize*

Like replication, an unbiased set of *independent data* is essential for estimating the error variance and for most statistical tests of treatment effects. Although truly unbiased data are unlikely, particularly in environmental studies, a randomized sampling method can help reduce bias and dependence of data and their effects on the accuracy of estimates of parameters. A systematic sample with a random start is one type of *randomization* (Krebs 1989). The goal with randomization is both to thoroughly sample the units (e.g., area, animals) of interest to capture the existing variability and to prevent the introduction of personal bias when an observer simply selecting units that are readily visible or otherwise easy to obtain.

Collecting data from “representative locations” or “typical settings” is not random sampling. If landowner attitudes preclude collecting samples from private land within a study area, then sampling is not random for the entire area and might not result in an unbiased sample. We say “might not” in the previous sentence because the outcome would depend, at least in part, on the characteristics of the specific location where access is denied. In studies conducted on representative study areas, statistical inference is limited to the protocol by which the areas are selected. If private lands cannot be sampled and public lands are sampled by some unbiased protocol, statistical inference is limited to public lands. The selection of a proper sampling plan is a critical step in the design of a project and may be the most significant decision affecting the utility of the data when the project is completed. If the objective of the study is statistical inference to the entire area, yet the sampling is restricted to a subjectively selected portion of the area, then there is no way to meet the objective with the study design. The inference to the entire area is reduced from a statistical basis to expert opinion.

*Control and Reduce Errors*

The precision of an experiment (i.e. the amount of random error in estimates) can be improved through increased replication, but this is expensive. As discussed by Cochran (1977) and Cox (1958), the precision of an experiment can also be increased through:

1. Control of related variables.
2. Refinement of the experimental techniques including greater sampling precision within experimental units.
3. Improved experimental designs, including stratification and measurements of non-treatment factors (covariates) potentially influencing the experiment.

***Control of related variables.*** Good experimental design should strive to improve the precision of conclusions from experiments through the *control (standardization) of related variables* (Krebs 1989). In the evaluation of the effect of some treatment (e.g., an anti-perching device) on the frequency of raptor perching on wind turbines, it would be most efficient to study the devices on the same model turbine, controlling for turbine type. One could evaluate the effect of wind turbines on bird use by making comparisons within vegetation types, and thus control for the effect of vegetation. However, standardization of related variables is often difficult in field studies.

An alternative to standardizing variables is to use information that can be measured on related variables in an *analysis of covariance* (Green 1979). For example, understanding differences in raptor use between areas is improved when considered in conjunction with factors influencing use, such as the relative abundance of prey in the areas.

Precision can also be improved by *stratification*, or assigning treatments (or sampling effort) to homogenous strata, or blocks, of experimental units. Stratification can occur in space (e.g., units of homogenous vegetation), and in time (e.g., sampling by season). Strata should be small enough to maximize homogeneity, keeping in mind that smaller blocks may increase sample size requirements. For example, if vegetation is used to stratify an area, then the stratum should be small enough to ensure a relatively consistent vegetation pattern within strata. However, stratification requires some minimum sample size necessary to make estimates of treatment effects within strata. It becomes clear that stratification for a variable (say vegetation type) at a finer and finer level of detail will increase the minimum sample size requirement for the area of interest. If additional related variables are controlled for (e.g., treatment effects by season), then sample size requirements can increase rapidly. Stratification also assumes the strata will remain relatively consistent throughout the life of the study, an assumption often difficult to meet in long-term field studies.

***Minimizing bias.*** Sampling (study) methods should be selected to minimize bias in the outcome of the study. Green (1979) provides several examples of bias introduced by study methods. In field studies it is probable that study methods will always introduce some bias. This bias can be tolerated if it is relatively small, measurable, or consistent among study areas. For example, the estimation of bird use within wind facilities and reference areas may be accomplished by visual observation. The presence of the observer no doubt influences bird use to some extent. However, if the observations are made the same way in both areas then the bias introduced by the study method should have little influence on the measured *difference in use* between the two areas, which is the parameter of interest. Methods introducing severe bias should be avoided.

***Size and distribution of study plots.*** The size and distribution of study plots also is an important component of the study method. Skalski et al. (1984) illustrated how field designs that promote similar capture (selection) probabilities in the different populations being compared result in comparisons with smaller sampling error. Green (1979) showed that plot size makes little difference if organisms are distributed at random throughout the study area, but that use of a larger number of smaller plots increases precision with aggregated distributions. Since aggregated distributions are the norm in nature, it generally is better to use a larger number of smaller plots well distributed throughout the study area or stratum.

Cost, logistics, the behavior of the organism being studied, and the distribution of the organism will determine plot size. Use of larger plots usually allows the researcher to cover more area at a lower unit cost (e.g. cost/hectare sampled). Also, plots can be so small that measurement error increases dramatically (e.g. is the study subject in or out of the plot) or the variance of the sample increases because the detection of the organism is rare, resulting in a data set with a lot of zeros. As a rule, the smallest plot size practical should be selected.

***Shape of study plots.*** The shape of study plots is an important consideration. For example, fixed plot and line-intercept sampling work well with common plant and animal species. In fixed plot sampling there is an attempt at complete census of some characteristic within selected units. Assuming some form of unbiased sampling is conducted, *fixed plot sampling* should result in equal probability of selection of each plot. *Point-to-item* and *line transect sampling* are more effective when sampling less common items. However, *line-intercept*, some point-to-item methods (e.g., plotless estimates of basal area), and some applications of *line transect* methods (e.g. when larger objects are more easily seen) are biased in that larger individuals are more likely to be included in the sample. Morrison et al. (2008) discussed various survey strategies including size and shape of survey plots in wildlife studies. *The selection of the appropriate size and shape of study plot must be made on a case by case basis and is an important component of the study protocol.*

*Pilot Studies*

A small data set can be powerful in aiding the design of environmental studies. Environmental studies should make maximum use of existing data. When little or no data exist, a pilot study can provide preliminary data useful in evaluating estimates of needed sample size, optimum sampling designs, data collection methods, the presence of environmental patterns and other factors which can affect the success of the study. Pilot studies can vary from reconnaissance surveys to the implementation of a draft protocol in a portion of the study area for a relatively short period of time. It may be false economy to try to save money by avoiding some preliminary data collection that could dramatically improve the quality of a study. In the absence of data on the study area, the first time period of study often becomes the pilot study. If the first period of study suggests major changes in the protocol, then the value of the first data set may be relatively low in the ultimate analysis of impacts, an important consideration for designs dependent on pre-impact data. A good example where pilot data may be very useful are experimental bias trials to understand searcher efficiency and carcass removal prior to determining the search interval and other important design considerations of expensive fatality studies. *While pilot studies are not absolutely necessary, they are recommended when the lack of data or delay due to study requirements are major concerns.*

*Practical Considerations for Study Designs*

Once the decision is made to conduct studies, the following issues must be identified and considered:

1. ***The area of interest*** (area to which statistical and deductive inferences will be made). Options include the facility site, the entire wind resource area (WRA), the local area used by animals of concern, or the animal population potentially affected (in this case population refers to the group of animals interbreeding and sharing common demographics).
2. ***Time period of interest.*** The period of interest may be (for example) diurnal, nocturnal, seasonal, or annual. Are the studies for risk or impact prediction (i.e., pre-construction), or for risk or impact estimation (i.e., post-construction)?
3. ***Species of interest.*** The species of interest may be based on behavior, fatalities in existing wind facilities, abundance, or legal/social mandate.

4. ***Potentially confounding variables.*** These may include landscape issues (e.g. large-scale habitat variables), biological issues (e.g. variable prey species abundance), land use issues (e.g. rapidly changing crops and pest control), weather, and study area access.
5. ***Time available to conduct studies.*** Given the project development schedule, the time available to conduct studies often will determine how studies are conducted and how much data can be collected.
6. ***Budget.*** Budget is always a consideration for potentially expensive studies. Budget should not determine what questions to ask but will influence how they are answered. It will largely determine the sample size, and thus the degree of confidence one will be able to place in the results of the studies.
7. ***Project magnitude.*** The size of the project or its potential impact often will determine the level of concern and the required precision.

## THE PHILOSOPHY OF STUDY DESIGN

Statistical conclusions are made under two broad and differing philosophies for making scientific inferences: *design/data-based* and *model-based*. Widespread confusion surrounds these philosophies, both of which rely on current data to some degree and aim to provide "statistical inferences." There is a continuum from strict design/data-based analysis to pure model-based analysis. The former are exemplified by finite sampling theory (Cochran 1977) and randomization testing (Manly 1991). Examples of the latter include global climate change models (Morrison et al. 2008) and habitat suitability indices/habitat evaluation procedures (HSI/HEP [US Fish and Wildlife Service (USFWS) 1980]) using only historic data (US Department of the Interior [USDOI] 1987). Often a combination of these two types of analyses is employed, resulting in inferences based on a number of interrelated arguments.

Wildlife studies also may be placed into two classes: *mensurative* and *manipulative* (Hurlbert 1984). *Mensurative* studies involve making measurements of uncontrolled events at one or more points in space or time, with space and time being the only experimental variable or treatment. Mensurative studies are more commonly called observational (Morrison et al. 2008) or monitoring studies. The following discussion will typically refer to mensurative studies as observational studies. Observational studies can include a wide range of designs including the BACI, line-transect surveys for estimating abundance, and sample surveys of resource use (Morrison et al. 2008). Surveys of abundance and resource use over large areas or for extended periods of time also are commonly referred to as monitoring studies and the following discussion will use this term as a special class of observational studies. *Manipulative* studies include much more control of experimental conditions; there always are two or more treatments with different experimental units receiving different treatments, and random application of treatments (Morrison et al. 2008). Pre-construction baseline and post-construction fatality studies typically are observational, while other post-construction studies may be observational or manipulative.

### Design/Data-Based Analysis

In strict design/data-based analysis, basic statistical inferences concerning the study areas are justified by the design of the study and data collected (Cochran 1977; Scheaffer et al. 1990). Computer intensive statistical methods (e.g., randomization, permutation testing, etc.) are available without requiring additional assumptions beyond the basic design protocol (e.g., Manly 1991). *Design/data-based statistical conclusions stand on their own merits for the agreed-upon:*

- Impact indicators
- Procedures to measure the indicators
- Design protocol

Re-analysis of the data at a later time cannot declare these basic statistical inferences incorrect. The data can be re-analyzed with different model-based methods or different parametric statistical methods; however, *the original analysis concerning the study areas will stand and possess scientific confidence if consensus is maintained on the conditions of the study* (bulleted items above).

**Model-Based Analysis**

Modeling is defined as the mathematical and statistical processes involved in fitting mathematical functions to data. Given this definition, models are included in all study designs. The importance of models and assumptions in the analysis of empirical data ranges from having little effect in design-based studies to being a critical part of data analysis in model-based studies. Design-based studies result in predicted values and estimates of precision as a function of the study design. Model-based studies lead to predicted values and estimates of precision based on a combination of study design and model assumptions often open to criticism.

Predictive methods estimate risk and impact through the use of models. In the extreme case of model-based analysis where no new data are available, all inferences are justified by assumption, are deductive, and are subject to counter-arguments. The more common model-based approach involves the combination of new data with parameters from the literature or data from similar studies by way of a theoretical mathematical/statistical model. An example of this approach in the evaluation of wind facility impacts on bird species is the demographic modeling of a bird population combined with use of radio-telemetry data to estimate the influence of the wind facility on critical parameters in the model. This approach is illustrated by the telemetry studies of golden eagles (*Aquila chrysaetos*) (Hunt 1995; Shenk et al. 1996; Hunt 2002) in Altamont Pass, California, as described by Shenk et al. (1996).

**Mixtures of Design/Data-Based and Model-Based Analyses**

Often inferences from study designs and data require mixtures of the strict design/data-based and pure model-based analyses. Mixtures of study designs would include those analyses where:

1. Design/data-based studies are conducted on a few important animal species.
2. Manipulative tests are conducted using surrogate species to estimate the effect of exposure to wind turbines on species of concern (Cade 1994).
3. Deductive professional judgment and model-based analyses are used to quantify impacts on certain components of the habitat in the affected area.

Strict adherence to design/data-based analysis in quantifying injuries may be impossible, but it is recommended that the design/data-based analysis be adhered to as closely as possible. *The* *value of indisputable design/data-based statistical inferences on at least a few impact indicators cannot be overemphasized in establishing confidence in the overall assessment of impact due to wind facilities.* However, in some circumstances model-based methods provide a suitable alternative to design/data-based methods. The advantages, limitations, and appropriate applications of model-based methods are discussed further in Chapter 4 and in Gilbert (1987), Johnson et al. (1989), and Gilbert and Simpson (1992).

**Observational Studies**

Observational studies associated with wind energy development and wildlife normally include pre-permitting baseline studies, risk assessment studies, and construction and post-construction monitoring studies designed to detect the relatively large effects of operating wind facilities. With the exception of monitoring studies, most post-construction studies involve detailed studies of one or more bird and bat populations and manipulative studies designed to determine the mechanisms of fatality or risk. These studies may include basic research on fatality pathways, the evaluation of risk and impact predictions, and the evaluation of risk reduction management practices. For the remainder of this section we consider designs that are most useful in pre-construction observational studies and post-construction monitoring. A more detailed discussion of the more complex post-construction studies will be taken up later in this appendix.

Pre-construction and post-construction monitoring studies generally will be useful to:

- Assist in screening potential development sites (i.e., macro-siting).
- Assist in the design of a selected wind energy site to reduce potential risk to wildlife species.
- Evaluate risk and impact predictions and to assist in the design of future phases of a project or new projects.
- Provide information useful in more complex studies (e.g. curtailment studies).

Studies to estimate risk and impacts of wind facilities typically will use an observational design with study areas not selected by a random procedure. Observational studies also are referred to as “sample surveys” (Kempthorne 1966), “planned surveys” (Cox 1958), and “unplanned experiments/observational studies” (NRC 1985). The objective of observational studies is usually an estimate of parameters necessary to describe the statistical population, such as density, survival rates, natality, and habitat use (Skalski and Robson 1992). In this case, the statistical population is defined as the group of animals or other objects of study. See Manly (1992), McKinlay (1975), Morrison et al. (2008) and Manly (2009) for excellent discussions of the design and analysis of observational studies.

An observational study of the impacts of a wind facility on wildlife species is not a true experiment because selection of the area to receive the wind facility and selection of the areas to be the references are not by a random procedure. The wind resource assessment area may consist of several disjoint subregions affected by wind turbines. These disjoint segments of the wind facility may be further stratified into major vegetation types. A potential undeveloped reference site may have areas within its boundary that appear similar to the wind facility and may also be stratified by the same major vegetation types. Even though the logic used in the study of these areas is that both the *assessment area* and the *reference area* are stratified into vegetation types, and study sites are randomly selected from within strata, these subregions are not independent replicates of the wind facility. Random selection of study sites/organisms from assessment and reference areas is known as *subsampling*. In the end, in an Impact-Reference study design, only one wind facility in one area is available for comparison to one or more subjectively selected reference areas.

## DESIGN/DATA-BASED STUDIES

Both design/data-based and model-based methods benefit from historic and current data collected according to repeatable and reliable field studies. This section contains designs that are most appropriate for observational studies, but can be used in manipulative studies. Studies following the recommended designs are repeatable. Statistical results from repeated sampling following the same design would apply to the same universe of study; whether the universe of study is an assessment area, an assessment population, or a time period of interest.

There are several alternative methods of study when estimating impact. The following designs are arranged approximately in order of reliability for sustaining confidence in the scientific conclusions. It must be understood that no one method is always best; the method selected for a particular study will depend on a number of issues, as discussed below.

Designs are discussed for studies that make comparisons between assessment areas and areas with similar physical and biological characteristics. These areas often are termed control areas but are not true controls in the experimental sense (i.e., a near perfect match to the assessment area). Since good control areas seldom exist in field studies, the term *reference area* is used instead. The term is defined in the same way as Stewart-Oaten (1986) and others have used the term *control area*: an area representative of the assessment area. The term “reference area” appropriately illustrates that, in observational studies, the differences between an assessment area and an area to which it is compared must be considered in light of the high degree of natural variability among any two sites.

### Designs with Control (Reference) Areas

*The Before-After/Control Impact Design (BACI)*

The *Before-After/Control (Reference)-Impact (BACI)* design is common in the literature (e.g., Stewart-Oaten 1986; Morrison et al. 2008), and has been called the “optimal impact study design” by Green (1979). It is equivalent to the paired control-treatment design proposed by Skalski and Robson (1992). The term *BACI* is so common in the literature that the letter *C* must be retained in its name, even though we use the term “reference area” rather than “control area.”

The BACI design is very desirable for impact determination because it addresses two major impact study design problems (Morrison et al. 2008):

1. Impact indicators, such as the abundance of organisms, vary naturally through time, so any change observed in an assessment area between the pre- and post-impact periods could conceivably be unrelated to the treatment (e.g., the construction and operation of a wind facility). Large natural changes are expected during an extended study period.
2. There always are differences in the indicators between any two areas (again, consider bird abundance). Observing a difference between assessment and reference areas *following* the treatment does not necessarily mean that the wind facility was the cause of the difference. The difference may have been present prior to construction. Conversely,

one would miss a wind facility impact if the abundance of the indicator on the reference area were reduced by some other perturbation concurrent with construction of the wind facility.

The BACI design helps with these difficulties. By collecting data at both reference and assessment areas using exactly the same protocol during both pre-impact and post-impact periods, one can ask the question: *Did the average difference in abundance between the reference area(s) and the wind facility area change after construction and start of operation?*

Notwithstanding these arguments, Manly (2009) points out some common problems with BACI studies including:

1. The assumption that the distribution of the difference between the assessment and reference area would not have changed with time in the absence of any manipulation is not testable, and making this assumption amounts to an act of faith; and
2. The correlation between observations taken with little time between them on both the assessment and reference areas is likely to be only partially removed by taking the difference between the results for the assessment and reference areas, with the result that the test for a manipulation effect is not completely valid.

The first problem has no solution because of the lack of control and environmental variation characteristic of field studies. Nevertheless, the use of multiple assessment and reference areas as suggested by Underwood (1994) can increase confidence in the determination of effect. When multiple assessment areas are not available (e.g., only one, small wind facility), then multiple reference areas can help to increase the confidence in results (i.e., do all of the reference areas show the same post-treatment response or trend). Manly (2009) recommends more complex time-series modeling as a possible way to overcome the second problem, although he cautions against its use with small data sets.

The BACI design is not always practical or possible. Adequate reference areas often are difficult to locate, and while preliminary analysis may satisfy the permitting agency that a project may proceed, the planning of a wind facility project does not always allow enough time for a full-scale pre-impact study period. The multiple time periods necessary for this design usually increase the cost of study. Additionally, alterations in land use or disturbance occurring over these time periods and reference areas complicate the analysis of study results. Caution should be used when employing this method in areas where potential reference areas are likely to incur relatively large alterations or changes that impact the species being studied. In the case of small homogeneous areas of potential impact and where a linear response is expected, the impact gradient design may be a more suitable design. If advanced knowledge of a wind facility location exists, the area of impact is somewhat varied, and species potentially impacted are wide ranging, the BACI design is preferred for observational studies of impact.

*Matched Pairs in the BACI Design*
Matched pairs of sites from assessment and reference areas often are subjectively selected to reduce the natural variation in impact indicators (Skalski and Robson 1992). Eberhardt (1976) labeled designs using this matching “pseudo-experiments” because of the lack of randomization and true replication of treatments and control conditions. Statistical analysis of these pseudo-experiments is dependent on the sampling procedures used for selection of sites and the amount of information collected on concomitant site-specific variables. For example, sites may

be randomly selected from the assessment area and each subjectively matched with a site from a reference area. In this case the area of inference is to the assessment area, and the reference pairs simply act as an indicator of baseline conditions.

When applied to a wind facility or other non-random perturbations (treatments), the extent of statistical inferences when matched pairs are used in the BACI design is limited to the assessment area. The inferences also are limited to the protocol by which the matched pairs are selected. If the protocol for selection of matched pairs is unbiased, then statistical inferences comparing the assessment and reference areas are valid and repeatable. The selection of matched pairs for extended study contains similar risks associated with stratification. The presumption is that, with the exception of the treatment, the pairs remain very similar – a risky proposition in long-term studies.

For additional examples of the use of this design refer to Morrison et al. (2008) and Manly (2009). Primary references for design and analysis are Skalski and Robson's (1992: Chapter 6) Control-Treatment Paired (CTP) design, Stewart-Oaten's (1986) Before/After-Control/Impact-Pairs (BACIP) design, and Manly (2009). If there are modifications of the basic structure of the design, then statistical analysis of the resulting data will not follow standard textbook examples.

**Impact-Reference Design (After Treatment)**

The *Impact-Reference Design* is considered because proposed and existing wind facilities often lack "before construction" baseline data from the assessment area and/or a reference area. In these cases, the BACI design is not applicable and an alternative must be found. The Impact-Reference Design is for quantification of impact where the impact indicators measured on the assessment area are compared to measurements from one or more reference areas. For example, data collected on avian use after the wind facility is operational are contrasted between the assessment and reference areas. Assessment and reference areas are censused or randomly subsampled by an appropriate observational design. Design and analysis of wind facility impacts in the absence of pre-impact data follow Skalski and Robson's (1992: Chapter 6) recommendations for accident assessment studies.

Differences between assessment and reference areas measured only after the impact might be unrelated to the impact, because site-specific factors differ. For this reason, differences in natural factors between assessment and reference areas should be avoided as much as possible. However, differences usually will exist. Reliable quantification of impact must include as much temporal and spatial replication as possible. Additional study components, such as the measurement of other environmental factors that might influence impact indicators, may also be needed to limit or explain variation and the confounding effects of these differences. Environmental indicators often are termed *covariates* because analysis of covariance may be used to adjust the analysis of a random variable to allow for the effect of another variable.

**Designs without Reference Areas**

*Before-After Designs*

The *Before-After Design* is for the quantification of impact when measurements on the assessment area before the impact are compared to measurements on the same area following the impact. This design is considered because it is possible that large-scale monitoring of animals within an area might be undertaken if enough concern exists for their security within a potential WRA. Government agencies or private industry may monitor impact indicators over long periods of time, and reliable baseline data may exist. If so, measurements can be made after the incident using exactly the same protocol and SOPs. However, observed differences might be unrelated to the incident, because confounding factors also change with time (see the above discussion of the BACI design). With respect to Before-After studies, the key question is whether the observations taken immediately after the incident can reasonably be expected within the expected range for the system (Manly 2009). Reliable quantification of impact usually will include additional study components to limit variation and the confounding effects of natural factors that may change with time.

Because of the difficulty in relating post-impact differences to treatment effects in the absence of data from reference areas, injury indicators can be particularly useful in detecting impacts using Before-After Design. The correlation of exposure to toxic substances and a physiological response in wildlife has been documented well enough for some substances to allow the use of the physiological response as a *biomarker* for evidence of impact. Examples of biomarkers used in impact studies include the use of blood plasma dehydratase in the study of lead exposure, acetylcholinesterase levels in blood plasma in the study of organophosphates, and the effect of many organic compounds on the microsomal mixed-function oxidase system in liver (Peterle 1991). The number of dead birds or bats in some defined area determined by necropsy to be caused by a wind facility could be used as such an indicator. It is possible that existing biomarkers (e.g., biomarkers indicating stress) might also have some application to estimating wind facility impacts on wildlife.

Costs associated with conducting the Before-After Design should be less than that required for designs requiring reference areas. Statistical analysis procedures include the time-series method of intervention analysis (Box and Tiao 1975; Rasmussen et al. 1993). An abrupt change in the impact indicator at the time of the impact may indicate the response is due to the perturbation (e.g., a wind facility). Scientific confidence is gained that the abrupt change was caused by the wind facility if the impact indicator returns to baseline conditions through time after making adjustments to factors in the wind facility apparently related to observed impacts (Figure 1) (Note that this figure, like the others in this appendix, is an idealized hypothetical presentation. Real data points would necessarily include error bars.)

If the impact indicator returns to baseline conditions during the operation of the wind facility, impacts would be considered short-term, suggesting the absence of long-term impacts. However, interpretation of this type of response without reference areas or multiple treatments is difficult and somewhat subjective. This type of design is most appropriate for short-term impacts, rather than for long-term projects such as a wind facility.

*Impact-Gradient Designs*

The *Impact-Gradient Design* is for quantification of impact in relatively small assessment areas on homogeneous environments. If potentially impacted species have relatively small home ranges (e.g. passerines) in a relatively homogenous landscape and a gradient of response is anticipated, this design can be an effective approach to impact studies. When this design is appropriate, treatment effects can usually be estimated with more confidence, and associated costs should be less than for those designs requiring baseline data and/or reference areas (Morrison et al. 2008).

Analysis of the Impact-Gradient Design is based on an analysis of the relationship between the impact indicator and distance from the hypothesized impact source—in this case, wind turbines. In effect, the assessment area includes the reference area on its perimeter. This design does not require that the perimeter of the assessment area be free of impact, only that the level of impact be different. If a gradient of biological response(s) or distance is identified, the magnitude of differences can be translated into what can be presumed to be at least a minimum estimate of the amount of impact. This Impact-Gradient Design would be analogous to a laboratory toxicity test conducted along a gradient of toxicant concentrations. An example might be an increasing rate of fledgling success in active raptor nests or an increase in passerine use of available habitat as a function of distance from the wind facility.

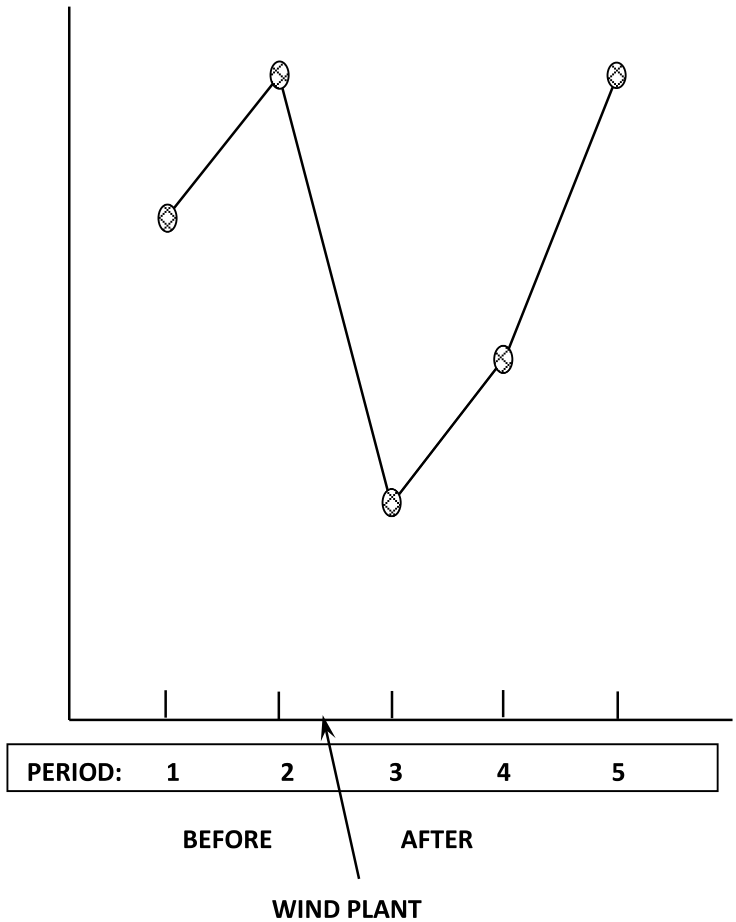


**Figure 1. Idealized sketch of an impact indicator in a Before-After Design with five time periods (T) of interest where an abrupt change coincides with an impact and is followed by a return to baseline conditions.**

In a field study, there likely will be naturally varying factors whose effects on the impact indicators are confounded with the effects of the impact. Thus it is important to have supporting measurements of covariates to help interpret the gradient of response observed in the field study. In the example of decreased mortality in passerines, an obvious covariate to consider would be vegetation type.

Data collected from these studies may also be analyzed from the philosophy of the designs with reference areas if one discovers that a gradient of response is absent but a portion of the study area meets the requirements of a reference area. The impact gradient design can be used in conjunction with BACI, Impact Reference and Before-After designs. Notwithstanding, Manly (2009) warns that the analysis of data from Impact Reference Designs may be complicated because: (1) the relationship between the impact and distance from the source many not be simple, necessitating the use of nonlinear regression methods; (2) the variation in observations may not be constant at different distances from the source; and, (3) there may be spatial correlation in the data.

## IMPROVING THE RELIABILITY OF STUDY DESIGNS

### Use of More than One Reference Area

Use of two or more reference areas increases the reliability of conclusions concerning quantification of impact (Underwood 1994). Reliability and validity of a scientific study for quantification of impact often will be questioned on the basis that "the reference area is not appropriate for the assessment area." Consistent relationships between the assessment area and each of two (or more) reference areas will generate far more scientific confidence in the results than if a single reference area is used. This scientific confidence likely will be increased more than would be expected given the increase in number of reference areas. This is true whether the wind facility is concluded to have "an important impact" or "no important impact." The use of multiple reference areas has the disadvantage of increased cost.

With two or more reference areas, one will be able to compare the impact indicators between different reference areas during the assessment period. Multiple reference areas also allow a comparison of impact indicators from the assessment area with the mean of impact indicators from two or more reference areas. For example, consider a wind facility and two reference areas outside the influence of but in the same general area as the wind facility. If approximately the same differences exist among the impact indicators on the wind facility and each of the reference areas before construction and the similarities among the reference areas persist after construction, then this "replication in space" usually gives scientists more confidence when making deductive professional judgments regarding post construction impacts.

In practice, impact indicators for the three areas will be plotted and examined for relative changes before and after construction of the wind facility. Assuming all three areas have similar trends in impact indicators before impact and reference areas have similar trends after impact, tests for differences will be between the mean of the impact indicators for multiple reference areas and the value of the impact indicator for the wind facility. By studying the effect of a few important covariates on the impact indicator on the wind facility and reference areas, it may be possible to adjust raw data before comparisons of mean values are made. For example, if nestling survival is highly correlated with prey abundance it might be possible to adjust survival rates for differences in prey on reference and assessment areas before testing for wind facility effects.

### Collection of Data over Several Time Periods

Collection of data on the study areas for several time periods before or after the impact also will enhance reliability of results as this replication in time increases confidence in the relationship of assessment and reference areas. Figure 2 illustrates results from a BACI design with two periods for data collection before the wind facility impact and two periods of data collection following the wind facility development. In this sketch there is only a slight indication of recovery after the construction of the facility. Statistical tests or other analyses (e.g., confidence intervals) unique to the subsampling plan used in data collection will be required for judging whether statistically significant differences exist between the point estimates.

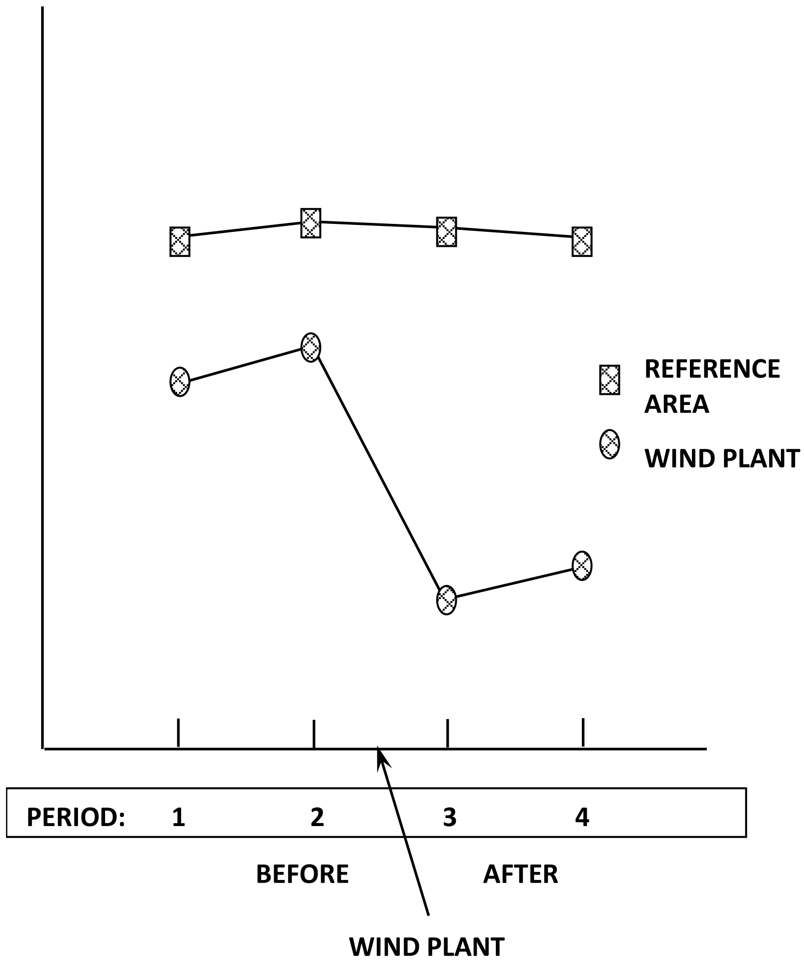


**Figure 2. Sketch of point estimates of an impact indicator in an idealized BACI design over four time periods with slight indication of recovery after the incident.**

For example, assume data on a response variable – say, the number of fledglings per active nest – exist for two years before construction and two years after construction for the wind facility and one reference area. Assume also that the data meet the assumptions necessary for use of *analysis of variance (ANOVA)*. ANOVA would be used to test for interaction among study sites and years, the primary indicator of an effect due to the development. A significant interaction effect may indicate that a pre-treatment difference between a development area and reference areas is not equal to the post-treatment difference. Additional comparisons could be made, such as the comparison of the mean response pre-treatment with the response each year post-treatment or with the mean over all years, post-treatment. Results would be presented graphically to illustrate point estimates and precision (confidence intervals or standard errors). The statistical inference would be limited to the two areas and the four years.

The specific test used depends on the response variable of interest (count data, percentage data, continuous data, categorical data, etc.) and the subsampling plan used (point counts, transects counts, vegetation collection methods, GIS data available, radio-tracking data, capture-recapture data, etc.). Often, classic ANOVA procedures will be inappropriate and computer-intensive methods will be required.

**Interpretation of Area-by-Time Interactions**

Non-parallel responses for impact indicators plotted over time on assessment and reference areas are said to exhibit *area-by-time interaction* (Figure 3).

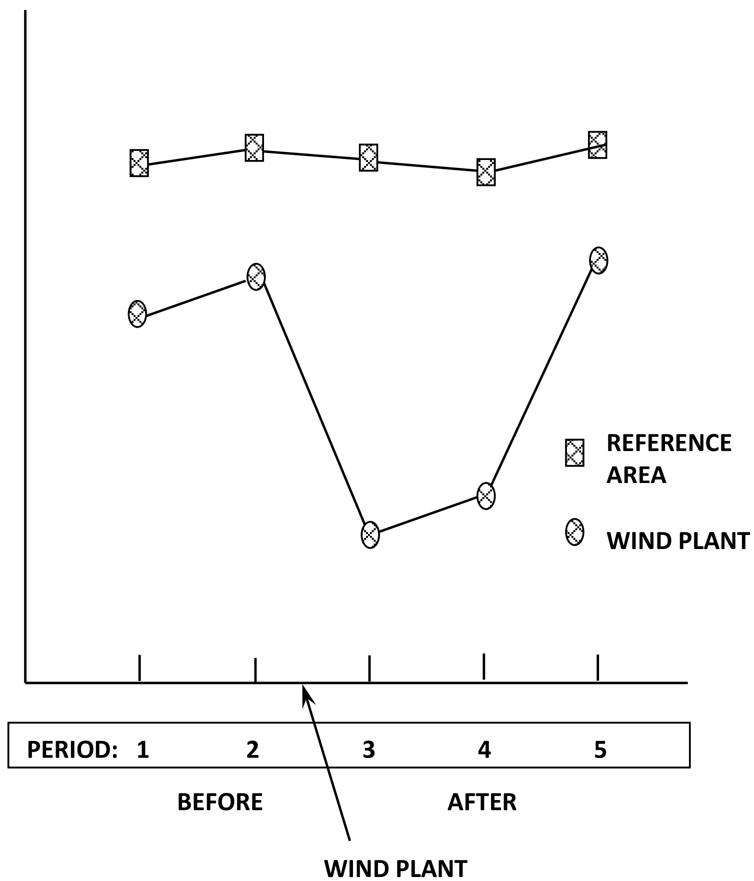


**Figure 3. Sketch of point estimates of an impact indicator in an idealized BACI design where interaction with time indicates recovery from impact by the third time period following the incident.**

If abrupt changes in the relationship of assessment and reference areas occur following the impact and are followed by a return to baseline conditions, then scientific confidence is gained for the conclusion that the abrupt changes were due to the impact. This interaction is illustrated in Figure 4, where the difference between the impact indicator on the reference and assessment areas represents the magnitude of an impact. Also, a return to a relationship similar to baseline conditions provides additional scientific confidence that comparison of assessment area and the subjectively selected reference areas is appropriate for estimating impact (Skalski and Robson 1992). In the case of a wind facility, recovery suggests a change in bird behavior reducing risk, a temporary impact due to construction, or a change in the wind facility (e.g., safer turbines).

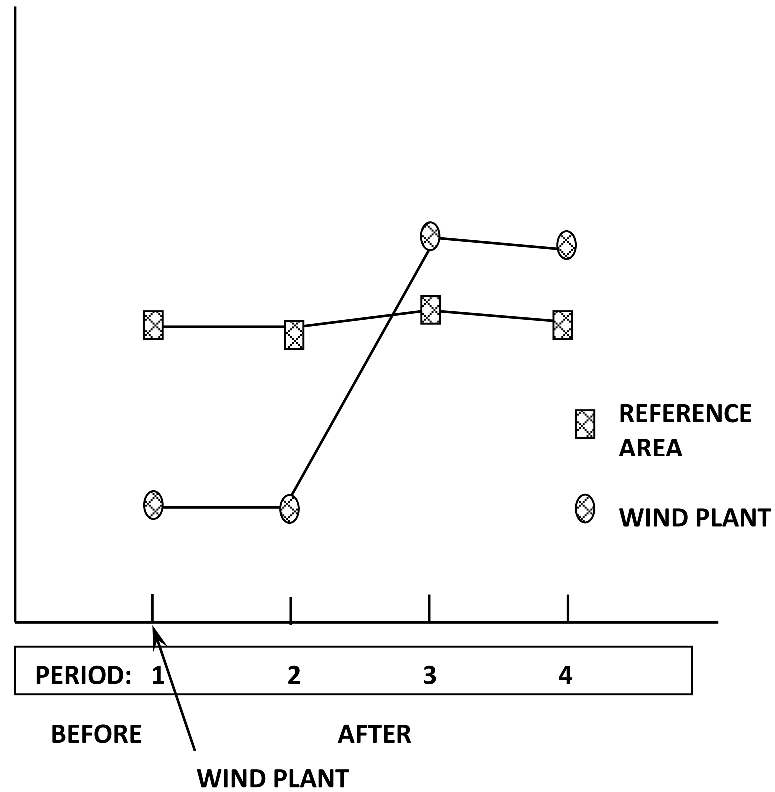


**Figure 4. Idealized sketch of results from a Reference-Impact Design where a large initial difference in the impact is followed by a shift to parallel response curves.**

Evidence of significant area-by-time interaction is especially important in an Impact-Reference Design, because this may be the only factor which aids in estimating the difference, if any, between the reference areas and assessment area in the absence of the impact. This situation is illustrated in Figure 4 with an idealized presentation of a large difference between the assessment and reference area following the impact, which is followed by a return to approximately parallel responses of data plotted over time. This interaction could indicate that impacts were temporary or that a significant change has been made in the operation of the wind facility (say installation of safer turbines or removal of turbines responsible for the impact).

### Model-Based Analysis

The use of models (of all types) increased dramatically beginning in the 1980s. In fact, modeling is now a focus of much interest, research, and management action in wildlife and conservation biology. But, as in all aspects of science, models have certain assumptions and limitations that must be understood before results of the models can be properly used. Modeling *per se* is neither good nor bad; it is the use of model outputs that determines the value of the modeling approach. The use of population models to make management decisions is becoming common. For example, such Advanced Experimental Design and Level 2 Studies models are playing a large role in management plans for such threatened and endangered species as the spotted owl (*Strix occidentalis*, all subspecies), desert tortoise (*Gopherus agassizii* ), Kirtland's warbler (*Dendroica kirklandii* ), and various kangaroo rats (*Dipodomys* spp.).

Morrison and Pollock (1997) sought to develop a useful, practical modeling framework for evaluating potential wind power plant impacts that can be generalized to populations of most bird species by: (1) reviewing the major factors that can influence the persistence of a wild population; (2) briefly reviewing various models that can aid in estimating population status and trend, including methods of evaluating model structure and performance; (3) reviewing survivorship and population projections; and (4) developing a framework for using models to evaluate the potential impacts of wind development on birds. Below we summarize the conclusions of Morrison and Pollock (1997) as a case study of how available data can be used to predict the potential changes in population numbers given varying degrees of mortality. The full background and rationale for their approach is found in the original publication.

Morrison and Pollock (1997) reviewed the parameters necessary to develop rigorous population-projection models. Life-history parameters are essential components of population-projection models. The characteristics that we collectively call life-history parameters of animals include quantifiable longevity, lifetime reproductive output, the young produced per breeding attempt, the age of dispersal, survivorship, sex ratio, and the time between breeding attempts. Combining various ranges of parameters can yield substantially different rates of population change. Such analyses provide information on whether the population can be sustained under varying expressions of life history traits. Once such relationships are understood, researchers have the opportunity to monitor selected life history traits as part of an assessment of the status of a population. A central part of impact assessment – such as in wind power plants – is developing a model that estimates the survival rates required to maintain a constant population. The strategy is to determine the survival rates required to sustain the populations that exhibit the various combinations of the other parameters governing population size. To be useful in a wide range of environmental situations and useable for people with varying expertise, the model should be based on simple mathematics (see discussion of the Leslie Matrix below).

Another objective of Morrison and Pollock (1997) was to evaluate the use of surrogates, or indices, of survival and population trends. For example, they found a highly significant negative relationship between adult survival and annual fecundity, suggesting that fecundity might be a suitable surrogate for survival in passerines and woodpeckers. This does not imply, however, that fecundity is a suitable indicator of abundance (i.e., increasing fecundity does not necessarily compensate for lower survival). To give another example, raptors will leave poor habitat (e.g., low food availability), often moving many kilometers in search of a suitable nesting site, and they tend to change territories more often when nesting is unsuccessful. Thus, as a generality, constancy of territory occupancy seems to be an indicator of good habitat quality in raptors. The number of nonbreeding, adult "floaters" in an area is an indicator of the general health of the bird population. This holds if territory availability is constant or increasing. An increase in the age of first breeding, as well as an increase in adult aggression, are possible indicators of a population at or above carrying capacity. In long-lived species with delayed age at first breeding, such as in many raptors and some waterbirds, changes in survival rates have a greater effect on the population than changes of similar magnitude in reproductive rates. Thus, the use of reproductive success in long-lived species as a population indicator should likely be supplemented with other indicators, such as territory occupancy and floater individuals. Surrogates serve primarily as a coarse filter to help narrow the scope of subsequent research.

## Use of Concomitant Site-Specific Variables

Often pure design/data-based analysis is not possible in impact studies. For example, bird abundance in an area might be estimated on matched pairs of impacted and reference study sites. However carefully the matching is conducted, uncontrolled factors always remain that may introduce too much variation in the system to allow one to statistically detect important differences between the assessment and reference areas. In a field study, there likely will be naturally varying factors whose effects on the impact indicators are confounded with the effects of the incident. Data for easily obtainable random variables that are correlated with the impact indicators (covariates) will help interpret the gradient of response observed in the field study. These variables ordinarily will not satisfy the criteria for determination of impact, but can be used in model-based analyses for refinement of the quantification of impact (Smith 1979; Page et al. 1993; Manly 2009).

For example, in the study of bird use on the Wyoming wind facility site, Western EcoSystems Technology (WEST), Inc. (1995) developed indices to prey abundance (e.g. prairie dogs, ground squirrels, and rabbits). These ancillary variables are used in model-based analyses to refine comparisons of avian predator use in assessment and reference areas. Land use is another obvious covariate that could provide important information when evaluating differences in wildlife use among assessment and reference areas and time periods.

Indicators of degree of exposure to the impact-producing factor also should be measured on sampling units. As in the Impact-Gradient Design, a clear impact-response relationship between impact indicators and degree of exposure will provide corroborating evidence of impact. These indicators also can be used with other concomitant variables in model-based analyses to help explain the “noise” in data from natural systems. For example, the size of turbines, the speed of the turbine blades, the type of turbine towers, and other turbine related factors can possibly be considered indicators of the degree of exposure.

## Uses of Modeling

In many model-based analyses of populations, a central part of impact assessment is development of a model predicting the survival rates required to maintain a population. The strategy is to determine survival rates required to sustain populations exhibiting various combinations of the other parameters governing population size. To be useful in a wide range of environmental situations and useable for people with varying expertise, the model must be based on simple mathematics.

Two general uses of models should be distinguished:

1. Providing insight into how an ecological system behaves.
2. Predicting the outcome of a specific situation.

In the first case, the model helps guide decisions when used in combination with other reliable data, whereas in the second case model assumptions and results must be tested in a quantitative manner (i.e., model validation).

## Types of Models

The following discussion focuses on the most prevalent model-based studies that are heavily dependent on assumptions and estimation procedures involving linear and logistic regression for data analysis (model-based sampling) and estimating and projecting population parameters into the future.

*Capture-Recapture Studies*
When observational characteristics make a census of organisms difficult, capture–recapture methods may be more appropriate for estimating population abundance, survival, recruitment, and other demographic parameters. In capture-recapture studies, the population of interest is sampled two or more times and each captured animal is uniquely marked. With capture-recapture studies, there is a concern with variation from both the sampling procedure and detectability (capture probability) issues related to the individuals under study. Some detectability issues can be solved through study design. Capture-recapture studies, and the extensive theory dealing with models for the analysis of these data, combine issues related to the sampling process with those related to the uncertainty regarding the appropriate explanatory model (Williams et al. 2002).

In general, sample plans should allow the study to meet the assumptions of the model being used to analyze the resulting data and allow the desired statistical inference. Below we briefly review a range of models that can be applied to wildlife-wind studies. For a general review of modeling of capture-recapture statistics we refer you to Pollock (1991) and Williams et al. (2002).

*Closed Population Mark-Recapture*
The Petersen-Lincoln model has been used for years by wildlife biologists to estimate animal abundance and is considered a closed population model. The Petersen-Lincoln model should be considered an index to abundance when a systematic bias prevents one or more of the assumptions described below from being satisfied. The assumption of closure is fundamental to the Petersen-Lincoln and other closed population models. Populations can increase or decrease through reproduction or immigration and mortality or emigration, respectively. The elimination of immigration and emigration is difficult in large and relatively mobile species. The success of mark-recapture studies with mobile populations often depends on the selection of study area boundaries grounded in this assumption. The assumption can best be met for small and relatively immobile species by keeping the interval between samples short. Lancia et al. (2005) reported 5-10 days as the typical interval, although the appropriate period between samples will be taxon-specific.

Otis et al. (1978) and White et al. (1982) offered a modeling strategy for making density and population size estimates using capture data on closed animal populations. With a complete capture history of every animal caught, these models allow relaxation of the equal catchability assumption.

*Population Parameter Estimation*
When studying animal populations, survival and recruitment may be of equal or greater interest than density or absolute abundance.

*Capture-Recapture Models*
Capture-recapture models originally focused on estimation of abundance and treated survival as a nuisance parameter to estimation of abundance (Williams et al. 2002). Beginning around the

1980s, however, survival estimation became a primary state variable of interest in wildlife population ecology. Here we provide a brief overview of several related topics with respect to parameter estimation.

The Cormack-Jolly-Seber model (Seber 1982; Williams et al. 2002; Amstrup et al. 2005, Chapters 5 and 9) allows estimation of abundance and survival and accounts for nuisance parameters (e.g., detectability, age, sex, etc.). This model is referred to as an open population model because it allows for gain or loss in animal numbers during the study. When open populations are sampled, this model provides a flexible and robust way of estimating population demographic parameters (Amstrup et al. 2005, p. 196). Note that the rate of gain, sometimes called the birth rate, could be recruitment and immigration, and the rate of loss, sometimes called the death rate, could be death and permanent emigration. Estimates of population size are computed using a Horvitz-Thompson estimator (McDonald and Amstrup, 2001; Taylor et al. 2002). Estimates of survival are obtained as part of the output of this model. Estimates of birth and death rates, if needed, can be derived from output of the Cormack-Jolly-Seber model. The flexibility of the approach is afforded by its ability to relate demographic parameters to extraneous study covariates. If the probability of survival or capture varies by characteristics that are known, even when the animal is not seen (e.g., age, sex, etc.), these characteristics can be used as covariates in a regression-like analysis (Amstrup et al. 2005, Chapter 9). Most types of capture heterogeneity can be accounted for this way, and hypotheses involving survival can be tested (Lebreton et al. 1992). For example, Amstrup et al. (2001) related catchability of polar bears to geographic regions in the study area. Regher et al. (2007) related survival of non-adult polar bears to the date of spring sea ice breakup in Western Hudson Bay. The assumption of equal probability of survival or capture of marked animals is not required under this modeling method. Lancia et al. (2005) pointed out that the distinction between open and closed populations is made to simplify closed population models and subsequent estimation of population parameters. The closed population simplifications (i.e., no gain or loss during the study) are expressed as assumptions and study design must assure these simplifying assumptions are met. Pollock (1982) noted that long-term studies often consist of multiple capture occasions for each period of interest. He reasoned that the assumption of closure was more likely to hold over shorter time periods, and subsequently proposed so-called robust designs. He showed that the extra information from capture occasions taken during periods of closure could be exploited to improve estimates of abundance and recruitment. Under Pollock's robust design, each sampling period consists of at least two subsamples, ideally spaced closely together so that the population can be considered closed to additions and deletions during that period. Kendall and Pollock (1992) summarized other advantages of the robust design.

*Survival Analysis*

Survival analysis is a set of statistical procedures for which the outcome variable is the *time until an event occurs* (Kleinbaum 1996). As such, survival analysis is concerned with the distribution of lifetimes (Venables and Ripley 2002). In wildlife research, survival analysis is used to estimate survival, or the probability that an individual survives a specified period (days, weeks, years). Because estimates of survival are used in population models, evaluations of changing population demography, and as justification for altering management practices, approaches to survival analysis have becoming increasingly common in wildlife research. Probably the most common approach to survival analysis in wildlife science is estimation using known fate data based on radio-telemetry where individuals are relocated on some regular basis. Another common application of time-to-event models has been recent work focused on estimating survival of nests where the event of interest is the success or failure of a nest (Stanley 2000; Dinsmore et al. 2002; Rotella et al. 2004; Shaffer 2004).

There are several general assumptions for time-to-event studies (see Pollock et al. 1989; Williams et al. 2002). First, we assume that radio-tagged individuals are a random sample from the population of interest. This assumption can be satisfied by using random location of trapping sites or perhaps stratifying trapping effort by perceived density of the population. We also assume that survival times are independent among different animals; violating this assumption leads to *overdispersion*. For example, if you catch a brood of quail (say six young) and radio-tag each, but a predator finds the brood and predates the hen and all the young – survival time between individuals was not independent. Additionally, we assume that radio transmitters (or other marks) do not affect the survival of marked individuals and that the censoring mechanism is random, or that censoring is not related to fate of the individual (e.g., a radio destroyed during predation or harvest event). For staggered entry studies, newly marked individuals have the same survival function as previously marked individuals.

*Occupancy Modeling*

*Occupancy modeling* is a recent entry into the field of capture-recapture analysis (MacKenzie et al. 2002; MacKenzie 2005). This approach stems from historical work done to confirm presence of a species in a particular location at a particular time, and as such relates data on site-specific features (e.g., canopy cover) to the presence of a species. Thus, the presence or absence of the feature can be used as a surrogate for abundance in monitoring temporal and spatial changes in species distributions (MacKenzie et al. 2006). Research on animal detectability has focused primarily on density or abundance estimation (e.g., Buckland et al. 2001, Williams et al. 2002), but more limited efforts have been expended on presence-absence approaches (Vojta 2005). Occupancy modeling focuses on estimating the proportion of an area of suitable habitat that is occupied by an individual of the species of interest (MacKenzie et al. 2004).

Occupancy surveys make the same general assumptions as most capture-mark-recapture studies as well as several specific assumptions (MacKenzie et al. 2006), including: (1) survey sites are closed to changes in occupancy over the survey season; (2) occupancy probabilities and detection probabilities are either constant across sites or a function of survey covariates; and (3) detections at each location are independent. Surveys for occupancy are usually less labor intensive than surveys for estimation of abundance in that both active (e.g., point-counts during breeding season) and passive approaches (e.g., track counts or hair snares) can be used to survey for presence. However, the difficulty becomes determining when a species is truly absent from the study plot, because failing to locate an individual during a survey does not imply absence (MacKenzie et al. 2006).

*Life Tables*

Life tables are one of the oldest means of examining mortality in animals; simply, they summarize survivorship by age classes in a cohort of animals. A basic life table requires only that age, the number of individuals surviving to the beginning of each age classification, and the number of deaths in each age class be known; mortality and survival rates can be calculated from these data. There is only one independent column in a life table; all the others can be calculated from entries in any one column. This dependency requires that great care be taken in constructing the table, and that large sample sizes be gathered.

*Simple Lotka Models*

The annual geometric growth rate of a population (*N*) is represented by *lambda*, also known as the finite rate of population increase. At time *t* the population size is *lambda* times its value at time *t* - 1, *Nt* = *lambda*(*Nt-1*). The population is increasing if *lambda* > 1, is constant if *lambda* = 1, and is decreasing if *lambda* < 1. For example, if *lambda* = 1.04, then the population was growing at the rate of 4% per period during the time sampled. For purposes of calculation, this formula is usually presented as $N_t = N_0 e^{rt}$, where *e* is the base of the natural logarithm, and *r* is the instantaneous rate of population increase (Johnson 1994).

*Leslie Matrix Models*

Leslie matrix models and similar stage-structured models can give great insight into the processes of population growth. The sensitivity of the population growth rate, *r*, to perturbations in vital rates for a Leslie-type model can be solved analytically. Understanding how growth rate changes in response to perturbations at various stages in the life table may help direct management strategies. For example, adult survival tends to be a parameter to which a model is extremely sensitive in long-lived species, whereas fecundity can be more important in short-lived species.

Matrix models subsume classical life table analysis as a special case but have capabilities that go far beyond that analysis. As summarized by McDonald and Caswell (1993), they: (1) are not limited to classifying individuals by age; (2) lead easily to sensitivity analysis; (3) can be constructed using the life cycle graph – an intuitively appealing graphical description of the life cycle; and (4) can be extended to include stochastic variation and density-dependent nonlinearities. McDonald and Caswell (1993) present a detailed description of the formulation and application of matrix models to avian demographic studies. The numbers in the body of the matrix are transition probabilities for survival and progression into other stages, while the numbers on the top row of the matrix represent stage-specific fecundity values. The term in any particular row and column can be thought of as the contribution of an individual in the age class represented by that column in year *t* to the age class represented by that row in year *t* + 1. The population can be projected from one year to the next by repeating the process into the future. Thus, we term this matrix the population projection matrix, or more popularly, the Leslie matrix after its developer (Leslie 1945).

A Leslie matrix can be built from estimates of fecundity and survival probabilities, and population growth may be projected for any number of time periods by pre-multiplying the age distribution at each time period by the Leslie matrix to get the new age distribution for the next time period. Creating population projections using Leslie matrices is a useful approach to the analysis of demography. They provide a numerical tool for determining growth rate and age structure of populations. The Leslie matrix also is useful for illustrating and studying the transient properties of populations as they converge to the stable state. Stage-based matrices, analogous to the age-based Leslie, can be used to analyze population growth for species in which it is difficult to age individuals, or where it is more appropriate to classify them into life stages or size classes rather than by age; these models are generally referred to as Lefkovitch (1965) stage-based models.

**Effective Population Size**

Small populations are susceptible to extinction because of demographic events, and in some species, loss of genetic variation. In a theoretical population, the rate of loss of genetic variation is inversely proportional to the population size. The reproductive behavior of natural populations is, of course, far from theoretical. To try to link natural and idealized populations, Wright (1931) defined the effective population size (*Ne*) as the size of an ideal population whose genetic composition is influenced by random processes in the same way as the natural population. When *Ne* is small, the population can rapidly lose genetic variation. However, *Ne* has no set relationship to actual population size, and its precise estimation is complex.

Various formulas have been developed to estimate the effective population size (e.g., Harris and Allendorf 1989; Nunney and Elam 1994). The demographic information needed to provide a reliable estimate of *Ne* can be difficult to obtain, and it is unlikely that this level of data collection will be indicated in most wind energy applications.

Additionally, there has been continuing debate over the minimum size a population must maintain to ensure long-term persistence (perhaps 100 generations). During the 1980s and into the 1990s, geneticists estimated that the minimum effective population size was 500 or more breeding individuals. New genetic evidence suggests, however, that this former estimate is far too low, and could easily range between 1000 and 10,000 individuals. This new estimate is based on consideration of the effect that mutations have on the fitness of the organism at low population sizes (Lande 1995; Lynch et al. 1995). It is difficult to make broad generalizations on the effective population size of organisms. For example, small populations (<100 adults) have been shown to persist for extended periods of time because of adaptations to local environmental conditions (e.g., Reed et al. 1986; Grant and Grant 1992; Nunney 1992). Evaluation of effective population size may be appropriate in preliminary analyses of a population. Such evaluations can help prioritize species to study and help determine the level of concern that should be placed on deaths in a population before initiating a full-scale population study.

### Model Evaluation

Bart (1995) provided an excellent review of the steps necessary in evaluating the appropriate uses of a population model. The following outline is summarized from his paper. There are three major components of model evaluation that should be included in all studies: model objectives, model description, and analysis of model reliability. The latter component is further divided into four important criteria.

### Model Objectives

As noted above, all studies should list the specific objectives for which model outputs will be used, and the reliability needed for those outputs. Will the output be used only as part of a much larger set of information or will management decisions be based on model results? The precision needed in all cases should be specified; there are no pre-established standards.

### Model Description

The general structure and organization of the model should be detailed. This description should include the basis for classifying the environment (e.g., vegetation types used for analysis), the number of sex and age classes, the behavior of the animals (e.g., breeding times, dispersal), and so on. For example, if sexes or age classes are lumped because of sample size considerations, then the behavior of the sexes and age classes is assumed to be equal. Likewise, if data on any aspect of the model are lumped across years, then time is held constant and assumed to have no overriding impact on the model. Most decisions reduce the complexity of the model, which in turn reduces its reality. Careful consideration and justification of any such decisions must be included in the model description.

## Analysis of Model Reliability

There are four major types of model reliability to evaluate: structure, parameter values, secondary predictions, and primary predictions. Each type should receive attention, with emphasis on the particular type that the management will focus on.

***Model structure.*** The realism of each assumption about the model should be fully assessed using any information available. Naturally, the first source of information here is the scientific literature about animal behavior, habitat relationships, population structure, and demographics. If little information is available on the species of interest, then data on related species should be consulted. The impact that each assumption should have on model results should be clearly discussed. Some assumptions likely will have minimal impact, while others may have potentially severe influence on the model. In some cases the decision will have to be made that insufficient information is available on the species of interest or closely related species for any meaningful evaluation of the model to be made. In such cases, the model – if developed – is of the purely descriptive form and should function only in identifying likely areas upon which field research (to fill the data gaps) should focus. However, information is usually available with which at least a preliminary model structure can be based.

***Parameter values.*** The most reasonable estimate of mean values and ranges for each parameter should be developed. Again, first the literature should be consulted. However, field studies may have to be conducted to provide reasonable estimates of certain parameter values. Unfortunately, the wildlife literature provides little in the way of strong data on survivorship of animals, especially where data on specific sex-age classes are needed. The reality of the situation usually demands that a short-term (1- to 3-year) study be initiated to provide the missing data. Because these studies usually focus on either rare species or isolated populations, it may be necessary to ignore yearly variations and lump across time to achieve an adequate sample size. As discussed above, the ramifications of this type of simplification must be carefully evaluated. It also is almost always the case that certain age classes (e.g., nonbreeding adults in raptors) will have to be combined; in most animals age cannot be readily determined after adulthood is reached.

***Secondary predictions of the model.*** Secondary predictions are intermediate outputs of the model that can be used to better understand the population and help evaluate the reliability of the final model. Each of these outputs is a function of two or more input variables. Comparing them to empirical data, to data for similar species, or just plain ecological common sense helps identify how reliable the model will be (and where weaknesses exist). Examples of secondary outputs include the distribution of age classes at first breeding, territory occupation, and so on.

***Primary predictions of the model.*** Primary predictions are the outputs of primary interest; this is the information used to determine project impacts and make management decisions. Predicted model results should be compared to reality either by comparing them with empirical data, or by running simulations that can be compared with known (past) population values. That is, if the model fits past (known) trends, then it is more likely to be properly forecasting future values. Unfortunately, little data are usually available because few animals have been adequately studied. Evaluations of models, however, are not truly independent if available empirical data are used to develop the model in the first place; testing the model predictions with the same data results in a biased validation.

## Modeling Synthesis

The goal should be to present a realistic and unbiased evaluation of the model. It is preferable to present both a best- and a worst-case scenario for model outputs, so that the range of values attainable by the model can be evaluated. For example, with a basic Leslie Matrix Model of population growth, knowing whether the confidence interval for the predicted (mean) value for *lambda* (rate of population growth) includes a negative value provides insight into the reliability of the predicted direction of population growth.

The process of model development and evaluation may show that the predictions of the model are sufficiently robust to existing uncertainties about the animal's behavior and demography that high confidence can be placed in the model's predictions. A poor model does not mean that modeling is inappropriate for the situation under study. Rather, even a poor model (i.e., a model that does not meet study objectives) will provide insight into how a population reacts to certain environmental situations, and thus provide guidelines as to how empirical data should be collected so that the model can be improved. Modeling is usually a stepwise process. Confidence intervals can be calculated to quantify the amount of variability associated with model outputs (Bender et al. 1996).

## Sampling the Area of Interest

In this section, the word *sample* means either *the process* by which units of observation in a specific area are selected, or *the actual collection* of units selected for study. The study area consists of either a finite or an infinite universe of sampling units. For example, a small site might be divided into a finite set of one meter by one meter plots, each having an opportunity to be selected in the sample. A sample of plots is selected from the area and measurements are made of indicators such as the number and biomass of plants or animals on each plot. In this case, the word sample refers more to the location of the units than to the specimen (plant, animal, sediment, etc.) collected from the unit.

If one is interested in the set of animals or plants living on (or influenced by) the assessment or reference study sites, then a second universe exists: namely, the population of animals or plants. The word *population* in this case refers to the group of organisms under study (the statistical population) and not necessarily to the biological population. This second universe also can be sampled and used to make statistical inferences to the group of organisms living in or influenced by the study area. For example, the impact of a wind facility on breeding pairs of raptors may extend out to 20 km from the turbines (determined by the range of the birds) and a capture-recapture model-based study may be undertaken of the breeding pairs within the WRA and a 20 km radius. In this case the marked animal is treated as the sample unit. All of the techniques for study of animal or plant populations in field ecology (plotless methods from forestry, capture-recapture methods from wildlife science, etc.) (Morrison et al. 2008) become candidates for study of the impacts of a wind facility.

*Two Levels of Sampling*

For a smaller wind facility with a less extensive assessment area, the entire area may be the study site, resulting in only one level of sampling. However, wind facilities may affect relatively large areas, in which case the larger area is "sampled" for study sites, and each of these sites is then sampled, resulting in two levels of sampling. In a study of raptor use on the 60,619 acres of the Wyoming WRA, for example, 18 study sites were selected for a second level of sampling (WEST 1995). In addition, present technology does not allow direct measurement of some environmental indicators (e.g., the number of passerine nests by species) on even moderately large areas. Destructive sampling, which permanently changes the sampled point or line (e.g., by removing vegetation), also may be required; and only a small part of the site can be destructively sampled without changing the very nature of the site.

If both levels of sampling occur according to an acceptable randomized design (i.e., a probability sample of available sites) then statistical inferences can be made to the entire study area. If selection of the second level of sampling units is a probability sample of the units, but the selection of the first level of units is ad hoc, then the statistical inference is only possible *to the study sites*. Inferences beyond the study sites to the assessment and reference areas will be *deductive* dependent on the protocol and SOP by which the first level of sites was selected.

It should not be surprising that two different studies on the same wind facility may yield conclusions that differ, given that:

1. Study sites within the wind facility may be selected using different criteria.
2. Subsampling protocols and SOPs for measurement (or estimation) of indicators at a site may differ between the two studies.

This again emphasizes the importance of rigorous selection and documentation of sampling protocols and SOPs so that the conclusions drawn from a study can be defended. It also illustrates the importance of having similar protocols for the study of impacts on animals by a new technology (wind turbines) in widely separated areas. However, even if identical areas, designs, and SOPs are used, results of studies based on independent sample units will fluctuate because of natural variation within the area and variation in the application of methods. Resolution of such apparently conflicting results may require intensive investigation of sampling designs, sampling protocols, sample processing, and data analysis by experts in the specific biological areas or study design and statistical analysis.

**Sampling Plans**

Statistical inferences can be made only with reference to the protocol by which study sites or study specimens are selected from the assessment and reference areas. Statistical inferences also are referenced to the protocol used for subsampling (or census) of units from sites and to the SOPs for measurement of impact indicators on subsampled units. Sampling plans can be arranged in four basic categories (Gilbert 1987):

1. Haphazard sampling
2. Judgment sampling
3. Search sampling
4. Probability sampling

Sampling plans that are most likely to be used during impact quantification associated with wind facility development are discussed below (see Gilbert 1987:19-23, Gilbert and Simpson 1992, and Johnson et al. 1989 for other common variations of probability sampling).

*Haphazard Sampling*
Gilbert (1987:19) noted that:

> "*Haphazard sampling* embodies the philosophy of 'any sampling location will do.' This attitude encourages taking samples at convenient locations (say near the road) or times, which can lead to biased estimates of means and other population characteristics. Haphazard sampling is appropriate if the target population is completely homogeneous… This assumption is highly suspect in most environmental studies."

Haphazard sampling has little role to play in providing data for statistical inferences, because results are not repeatable. Information from haphazard sampling may be appropriate for preliminary reconnaissance of an area, but the information can be used only in making deductive arguments based on professional judgment.

*Judgment Sampling*
"*Judgment sampling* means subjective selection of population units by an individual [the researcher]" Gilbert (1987:19).

Gilbert is not much more enthusiastic about judgment sampling than haphazard sampling:

> "If the [researcher] is sufficiently knowledgeable, judgment can result in accurate estimates of population parameters such as means and totals even if all population units cannot be visually assessed. But it is difficult to measure the accuracy of the estimated parameters. Thus, subjective sampling can be accurate, but the degree of accuracy is difficult to quantify" (1987:19).

As in haphazard sampling, judgment sampling may be appropriate for preliminary reconnaissance of an area, but has little role to play in providing data for statistical inferences, because results are not repeatable. Judgment sampling can be used to develop data for models of natural systems (Morrison et al. 2008), and can play a role in understanding and explaining the magnitude and duration of an impact. When judgment sampling is used, inferences are deductive and depend on professional judgment.

*Search Sampling*
Search sampling is a form of judgment sampling that requires historical knowledge or data indicating where the resources of interest exist. For example, a study of factors causing bird fatalities might be limited to the portion of the wind facility where bird use is common. Searching for "hot spots," which is discussed more fully under the "cost cutting procedures" section below, is a form of search sampling. The validity of this procedure depends on the accuracy of the information guiding where and when to search. The procedure also places a great deal of emphasis on the collection of accurate data over time and space to guide the search. As with other non-probability sampling, statistical inference is limited by the protocol used in the selection of study sites and in the collection of data within these sites.

*Probability Sampling*
*Probability sampling* refers to the use of a specific method of *random* selection of subjects for study (e.g., sites, units, individuals) from the universe subjects available for study (Gilbert 1987:20). Randomization is necessary to make probability or confidence statements concerning the magnitude and/or duration of impact (Johnson et al. 1989). Examples of random sampling plans include simple random sampling (random sampling), stratified random sampling (stratified sampling), random start systematic sampling (systematic sampling), and sequential random sampling (sequential sampling).

These sampling plans (and others, especially for mobile animals) can be combined or extended to give a wide array of possibilities. Johnson et al. (1989: 4-2) recommend: "If other more complicated sample designs are necessary, it is recommended that a statistician be consulted on the best design, and on the appropriate analysis method for that design."

***Random sampling.*** Random sampling requires that the location of each sample site (unit) be selected independently of all other sites (units). Such sampling plans have "nice" mathematical properties, but random locations are usually more clumped and patchy than expected. In studies with small sample sizes, which are common in wildlife studies, entire regions of special interest may be under- or over-represented (Morrison et al. 2008). Some scientists mistakenly believe that random sampling is always the best procedure. Random sampling should be used in assessment or reference areas (sites) only if the area is very homogeneous with respect to the impact indicators and covariates. Because this is seldom, if ever, the case, researchers should try to avoid relying solely on random sampling.

***Stratified random sampling.*** Stratified sampling with a random start is a randomization procedure designed to guarantee that the sampling effort will be spread out over important subregions called strata, which are identified in advance. Important strata are identified, and sites within strata are selected for study. Similarly, sites might also be stratified for subsampling. The specific procedure by which locations for sample sites within strata (units within sites) were established (i.e., randomly or systematically) must be clearly elucidated.

Ideally, strata should be homogeneous with respect to the variable (e.g., animal density) and covariates (e.g., vegetation type) of interest (Morrison et al. 2008). Strata may be subareas on a map of the known range of the species of interest. Stratification also may be by reference to some known characteristic of the species of interest (e.g., areas of high and low numerical density) or by some environmental variable (e.g., vegetation type) potentially influencing the species' response to a perturbation.

Strata must not overlap, and all impact/reference areas of interest must be included. Study sites (sampling units) must not belong to more than one stratum. Also, statistical inferences cannot be drawn toward differences in impact indicators for any portion of strata unavailable for sampling. It may be possible to make professional judgments concerning the magnitude and duration of impact on those areas, but conclusions will be made without the aid of inductive statistical results. As an example, in the studies of golden eagles in Altamont (Hunt et al. 1995) some private lands were not accessible for trapping eagles. The resulting relocation data must be analyzed with the knowledge that the radio-tagged sample is not a random sample of the population.

Often stratification will be used in impact studies for quantification of impact within strata and for contrasting the impacts of the incident between strata. For example, it may be of interest to investigate the impacts of a wind facility in different vegetation types (a potential stratification) where the objective is to make statistical inference to each vegetation type within the wind facility. This type of analysis is referred to as using "Strata as domains of study... in which the primary purpose is to make comparisons between different strata..." (Cochran 1977: 140). In this situation, the formulas for analysis and for allocation of sampling effort (Cochran 1977: 140-141) are quite different from formulas appearing in introductory texts such as Scheaffer et al. (1990). The standard objective considered in textbooks is to minimize the variance of summary statistics for all strata combined (e.g., the entire wind facility).

It is usually stated in textbook examples that a primary objective of stratification is improved precision based on optimal allocation of sampling effort into more homogeneous strata. The problem with this objective is that it may be possible to create homogeneous strata with respect to one primary indicator (or a few indicators), but there are often many indicators measured. It is very unlikely that the units within strata will be homogeneous for all of them. For example, one could stratify a study area based on vegetation and find that the stratification works well for indicators of impact associated with overstory vegetation. But because of management (e.g., grazing), understory vegetation might be completely different and make the stratification unsatisfactory for indicators of impact measured in the understory. Further, anticipated reduction in variance for the primary indicators may not occur or may be in the range of 5% to 10% and thus not substantially better than random sampling. Systematic sampling with post-classification into domains of interest (subpopulations) in the spirit of the US EPA Environmental Monitoring and Assessment Program (Overton et al. 1991) may perform better than stratified random sampling. (See the discussion on systematic sampling below.)

Factors on which to stratify in quantification of impact associated with wind facility development could include physiography/topography, vegetation, land use, turbine type, etc. Strata should be relatively easy to identify by the methods that will be used to select strata and study sites within strata, and of obvious biological significance for the indicators of impact. Spatial stratification is a major help when a study is of relatively short duration and very few sites (units) are misclassified. However, some potential study sites will be misclassified in the original classification (e.g., a pond on the aerial photo was actually a parking lot). The short-term study may turn into a long-term study in which interests migrate toward complicated analysis of subpopulations (Cochran 1977: 142-144) which cross strata boundaries, and strata may change (e.g. the corn field has become a grassland). In long-term studies, the stratification procedure will be most favorable at the beginning of the study. Benefits of stratification on characteristics such as vegetative cover type, density of prey items, land use, etc. diminish quickly as these phenomena change with time.

A fundamental problem is that strata normally are of unequal sizes and, thus, units from different strata have different weights (importance values) in any overall analysis to be conducted. Consider the relatively complex formulas for computing an overall mean and its standard error based on stratified sampling (Cochran 1977: 87-95). In the analysis of subpopulations (subunits of a study area) which belong to more than one stratum (Cochran 1977: 142-144), formulas are even more complex for basic statistics such as means and totals. The influence of these unequal weights in subpopulations is unknown for many analyses such as ordination or multidimensional scaling. Many analyses of studies ignore these unequal weights and assume the units from different strata are selected with equal probability.

Stratification often is based on maps, but studies usually suffer from problems caused by inaccurate maps or data concerning impact sites, reference sites, and vegetation types at the time study sites are randomly selected. There are two basic problems:

1. Misclassified sites have no chance of selection in the field SOPs used by investigations.
2. Unequal probability of site selection is introduced *within strata*.

It may be necessary to stratify with little prior knowledge of the study area; but if possible, stratification should be limited to geographic stratification with excellent maps, and the minimum number of strata should be used (preferably no more than three or four). Covariates that are potentially correlated with the magnitude and duration of impact should be measured on the study sites (or on subsampling units within sites). Some analyses such as ordination and multidimensional scaling may require additional original mathematical research for justification of their use. The bottom-line on stratified sampling is that the study should be no longer than the strata can endure, the strata should be homogeneous for the variables and covariates of interest and the strata should be of obvious biological significance for the variables and covariates of interest (Morrison et al. 2008).

***Systematic sampling**.* In systematic sampling, the sampling frame is partitioned into units of study and samples are selected from the units in accordance with a systematic protocol. Systematic sampling distributes the locations of samples uniformly through the list or over the area (site) (Morrison et al. 2008). If a random starting rule is followed (Foreman 1991), the systematic sample has similar properties to a simple random sample and inferences can be made in a similar manner (Morrison et al. 2008). Mathematical properties are not as "nice" as for random sampling, but generally the statistical precision is better (Scheaffer et al. 1990). Systematic sampling has been criticized for two basic reasons. First, the arrangement of points may fall in step with some unknown cyclic pattern in the response of impact indicators. This problem is addressed a great deal in theory, but is seldom a problem in practice. Known cyclic patterns in the area should be used to advantage to design a better systematic sampling plan.

Second, in classical finite sampling theory (Cochran 1977), variation is assessed in terms of how much the result might change if time could be backed up and a different random starting point could be selected for the uniform pattern. For a single uniform grid of sampling points or plots (or a single set of parallel lines) this is impossible, and thus variation cannot be estimated in the classical sense. Various model-based approximations have been proposed for the elusive measure of variation in systematic sampling (Wolter 1984).

Aside from the criticisms, systematic sampling works very well in the following situations:

1. Design/data-based analyses conducted as if random sampling had been conducted (effectively ignoring the potential correlation between neighboring locations in the uniform pattern of a systematic sample [Gilbert and Simpson 1992]).
2. Encounter sampling with unequal probability (Overton et al. 1991; Otis et al. 1993).
3. The model-based analysis commonly known as "spatial statistics," wherein models are proposed to estimate impact using the correlation between neighboring units in the systematic grid (see, for example, Kriging [Johnson et al. 1989: chapter 10]).

The design and analysis in Case (1), above, is often used in evaluation of indicators in relatively small homogeneous study areas or small study areas where a gradient is expected in measured values of the indicator across the area. Ignoring the potential correlation and continuing the analysis as if it is justified by random sampling can be defended, especially in impact assessment, primarily because from a statistical perspective the analysis is conservative. Estimates of variance treating the systematic sample as a random sample will tend to overestimate the true variance of the systematic sample (Hurlbert 1984; Scheaffer et al. 1990; Thompson 1992, 2002). The bottom line is that systematic sampling in relatively small impact assessment study areas following Gilbert and Simpson's (1992) formulas for analysis is a good plan. This applies whether systematic sampling is applied to compare two areas (assessment and reference), the same area before and following the incident, or between strata of a stratified sample.

One of the primary reasons given for preference of stratified sampling (see above) over systematic sampling is that distinct rare units may not be encountered by a uniform grid of points or parallel lines. Hence, scientists perceive the need to stratify, such that all units of each distinct type are joined together into strata and simple random samples are drawn from each stratum. As noted above, stratified random sampling works best if the study is no longer than the strata can endure, no units are misclassified, and no units change strata during the study. Systematic sampling has been proposed to counter these problems (Overton et al. 1991; Morrison et al. 2008). Unequal probability sampling is almost inescapable, but to a large extent, the problems associated with misclassified units and units that change strata over time can be avoided. For long-term impact assessment or monitoring, or when problems with misclassification and changes in land use are anticipated, one should consider systematic sampling strategies (Morrison et al. 2008; Overton et al. 1991). Multi-stage sampling (i.e., subsampling) using stratified (or random) sampling with the intent of capturing data from rare units can be an effective design.

*Cost-Cutting Sampling Procedures*
One of the biggest problems with large-scale field studies is that they are very expensive. Estimating the number of birds of a large number of species using an area is a prime example. Some of the standard sampling procedures that may reduce costs of fieldwork are presented below. These techniques should be considered in design of all field studies.

***Double sampling and Smith's two-stage sampling procedure****.* The basic idea of double sampling is that easy-to-measure/economical indicators are measured on a relatively large subset or census of sampling units in the assessment and reference areas. In addition, the expensive/time-consuming indicators are measured on a subset of the sampling units from each area. As always, easily obtainable ancillary data should be collected. Analysis formulas are available in Cochran (1977). The ideas for double sampling are simple to state and the method is easy to implement.

Smith's (1979) two-stage sampling procedure is a variation of the general double sampling method. Basically, Smith's suggestion is to over-sample in an initial survey when knowledge concerning impacts is most limited, and to record economical easy-to-measure indicators. For example, bird use (an index to abundance sampled according to a probability sample) might be taken during a pilot study, allowing one to identify species most likely affected. In the second stage and with the benefit of pilot information gained, the more expensive and time-consuming indicators (e.g., the actual number of individuals) might be measured on a subset of the units. If the correlation between the indicators measured on the double-sampled units is sufficiently high, precision of statistical analyses of the expensive/time-consuming indicator is improved. For a more detailed discussion of double sampling please refer to Morrison et al. (2008).

***Ranked set sampling****.* Ranked set sampling is a technique originally developed in estimation of biomass of vegetation during study of terrestrial vegetation; however, the procedure deserves much broader application (Stokes 1986; Muttlak and McDonald 1992; Patil et al. 1994). The technique is best explained by a simple illustration. Assume 60 uniformly spaced sampling units are arranged in a rectangular grid in a WRA. Measure a quick, economical indicator of animal risk (say bird use) on each of the first three units, rank-order the three units according to this indicator and measure an expensive indicator (say bird fatalities) on the highest ranked unit. Continue by measuring bird use on the next three units (numbers 4, 5, and 6), rank order them, and measure fatalities on the second-ranked unit. Finally, rank order units 7, 8, and 9 by bird use and measure fatalities on the lowest ranked unit; then start the process over on the next nine units. After, completion of all 60 units, a "ranked set sample" of 20 units will be available on the fatalities. This sample is not as good as a sample of size 60 for estimating the number of bird fatalities, but should have considerably better precision than a standard sample of size 20.

Ranked set sampling is most advantageous when the quick, economical indicator is highly correlated with the expensive indicator, and ranked set sampling can increase precision and lower costs over simple random sampling (Mode et al. 2002). These relationships need to be confirmed through additional research. Also, the methodology for estimation of standard errors and allocation of sampling effort is not straightforward.

***Sequential sampling****.* In sequential sampling, a statistical test is used to evaluate data after the impact indicator is measured on a subset of units or batch of units selected for sampling (Johnson et al. 1989: Chapter 8; Mukhopadhyay et al. 1992). The results of each sequential test determine whether another subset of sampling units or batch of units will be collected and analyzed. The procedure has obvious advantages in certain situations where a large number of samples are collected for laboratory analysis. In field studies, the estimate of certain biases, such as the estimate of scavenger removal of carcasses by monitoring carcasses placed in the field, might benefit from sequential sampling.

Johnson et al. (1989) presented the basic formulas for sequential analysis using simple random sampling. However, any variation in the simple random sampling protocol (or simple systematic sampling protocol) results in computational requirements not described in standard textbooks. Unexpected complexities are introduced into statistical procedures, because the “sample size” is a random variable (i.e., one cannot determine in advance the number of sampling units which will be analyzed).

***Adaptive sampling.*** In adaptive sampling the procedure for selecting sites or units to be included in the sample may depend on values of the variable of interest observed during the survey (Thompson and Seber 1996; Thompson 2002; Smith et al. 2004). Adaptive sampling takes advantage of the tendency of plants and animals to aggregate and uses information on these aggregations to direct future sampling. Adaptive sampling could be considered a method for systematically directing search sampling.

As an example of adaptive sampling, suppose the wind facility is divided into a relatively large number of study units. A survey for bird carcasses is conducted in a simple random sample of the units. Each study unit and all adjacent units are considered a “neighborhood” of units. With the adaptive design additional searches are conducted in those units in the same neighborhood of a unit containing a carcass in the first survey. Additional searches are conducted until no further carcasses are discovered. As with sequential sampling, computational complexities are added because of the uncertainty of the sample size and the unequal probability associated with the selection of units.

***Generalized random-tessellation stratified designs.*** Generalized random-tessellation stratified designs (GRTS; Stevens and Olsen 1999, 2004), were developed to assist with spatial sampling of natural resources (Morrison et al. 2008). GRTS designs assume that segments of a population are more similar the closer they are in space. Sampling procedures are designed so that they are stratified and spatially balanced across the landscape (Stevens and Olsen 2004).

***Searching for hot spots.*** Methods of searching for hot spots (i.e., areas within the assessment area which have high values of the impact indicator) may be valuable under certain conditions — including the evaluation of whether impacts are significant and continuing. Johnson et al. (1989: Chapter 9) model a hot spot as a localized elliptical area with values of the impact indicator above a certain standard. If a sampling study does not find hot spots, then confidence is gained in the conclusion that the area is not impacted above the standard or that impacts are not continuing above the standard. Techniques involve systematic sampling from a grid of points arranged in a certain pattern and judgment that there are no hot spots of impact if none of the points yield values above a given standard. This technique will be most applicable in wind facility monitoring studies where regulatory standards for mortality exist, the study is of limited duration, and no reference areas are available.

Johnson et al. (1989: Chapter 9) provided a thorough introduction to the technique and gave the analyses for two basic approaches. If hot spots are detected then a decision must be made whether it is necessary to fully quantify the impact over the assessment area or just within the hot spots. For wind facilities, monitoring for mortality might consider this approach if more extensive sampling suggest hot spots (e.g., end row turbines, turbines near wetlands, etc.). However, more extensive monitoring may be required to identify hot spots, if bird use of the wind facility changes.

***Monitoring revisit design.*** The survey designs for environmental monitoring are greatly enhanced by the use of panels to identify which sample units are surveyed on each visit through time. A panel is a collection of sample units that are always sampled at the same time (Fuller 1999). The frequency and pattern at which panels are visited through time is the revisit design (McDonald 2003). In environmental monitoring there is dynamic tension between the objective of estimating trend over a period of years and estimating status in any given year. The revisit design reflects the relative importance of each monitoring objective.

Visiting a set of sample units every year (pure panel) ensures low variance for trend estimates, but in the case of sampling some subjects such as plants, the sites tend to wear out and obtain biases through conditioning, particularly when destructive sampling is used (Fuller 1999; McDonald 2003). Visiting a set of sites in alternating years (rotating panel) allows for the inclusion of more sites in the sample (increasing the chance of observing rare elements) and reducing cost and results in low variance for the estimation of mean levels (status) within a year (Fuller 1999; McDonald 2003). Urquhart and Kincaid (1999) found the pure panel to be the best for detecting linear trends through time and revisiting new sample units each time to be the best for estimating status. Revisit designs for biological monitoring balance the objectives for status and trend estimation equally as suggested by McDonald (2003), Fuller (1999), Breidt and Fuller (1999), and Urquhart et al. (1998).

McDonald (2003) provided several examples of revisit designs. The split panel revisit design may have particular application for large scale or long-term monitoring studies. The split panel includes a panel (group of sample units) that is visited every survey period, and several panels that are visited in rotating sampling periods. For example, one panel might be surveyed each visit during a year and four panels might be surveyed once every fourth visit. This split panel design has been shown to provide the most power for estimating status and trend (Breidt and Fuller 1999; Urquhart and Kincaid 1999).

***Methods of probability sampling.*** Regardless of the sampling design of a study, data must be collected either in plots, along lines, using a plotless sampling method, or through some form of model-based sampling. For a detailed description of these methods please refer to Morrison et al. (2008).

In the cases where the probability of selection is influenced in some predictable way by some characteristic of the object or organism, this bias must be considered in calculating means and totals (Morrison et al. 2008). Examples include line intercept sampling of vegetation (McDonald 1980; Kaiser 1983), aerial transect methods for estimating big game numbers (Steinhorst and Samuel 1989; Trenkel et al. 1997), and the variable circular plot method for estimating bird numbers (Reynolds et al. 1980). If the probability of selection is proportional to some variable, then equations for estimating the magnitude and mean for population characteristics can be modified by an estimate of the bias caused by this variable.

***Fixed area plot.*** Sampling a population is usually accomplished through a survey of objects (e.g., animal carcasses) in a collection of known size sample units. The survey is assumed complete (e.g., a census), so the only concern is plot-to-plot variation. Estimating the variance of these counts uses standard statistical theory (Cochran 1977). Results from the counts of organisms on sample units are extrapolated to area of interest based on the proportion of area sampled.

Sampling by *fixed plot* is best done when organisms are sessile (e.g., plants) or when sampling occurs in a short time frame such that movements from plots have no effect (e.g., avian use surveys) (Morrison et al. 2008). We assume, under this design, that counts are made without bias and no organisms are missed. If counts have a consistent bias or organisms are missed, then estimation of total abundance may be inappropriate (Anderson 2001) unless biases can be estimated. Aerial surveys are often completed under the assumption that few animals are missed and counts are made without bias. However, as a rule, total counts of organisms, especially when counts are made remotely such as with aerial surveys, should be considered conservative. Biases are also seldom consistent. For example, aerial counts are likely to vary depending on the observer, the weather, ground cover, pilot, and type of aircraft. When there are known biases (e.g., detection bias), they can be estimated and used to adjust the counts.

***Line intercept sampling.*** The objective in *line intercept sampling* is estimation of parameters of two-dimensional objects in a two-dimensional study area (Morrison et al. 2008). The basic sampling unit is a line randomly or systematically located perpendicular to a baseline and extended across the study area. In wildlife studies, the objects (e.g., habitat patches, fecal pellets groups) will vary in size and shape and thus will be encountered with a bias toward larger objects relative to the baseline. This *size bias* does not affect the estimate of aerial coverage of the objects but may bias estimates of other parameters. For example, estimates of age or height of individual plants would be biased toward the larger plants in the study area. Estimates of these parameters for the study area must be corrected for this source of bias.

The primary application of line intercept sampling has been to estimate coverage by the objects of interest (Canfield 1941). The procedure also has been used to record data on attributes of encountered objects (Lucas and Seber 1977; Eberhardt 1978; McDonald 1980; Kaiser 1983), to estimate a variety of parameters including the aerial coverage of clumps of vegetation, coverage and density (number per unit area) of a particular species of plant, number of prairie dog burrows, and the coverage by different habitat types on a map (Morrison et al. 2008).

***Plotless point sampling.*** Plotless methods from sample points using some probability sampling procedure are considered more efficient than fixed area plots when organisms of interest are sparse and counting of individuals within plots is time consuming (Ludwig and Reynolds 1988). The most common applications of plotless methods are line transect surveys and variable area circular plots.

***Line transects.*** *Line transects* are similar to line intercept sampling in that the basic sampling unit is a line randomly or systematically located on a baseline, perpendicular to the baseline, and extended across the study region (Morrison et al. 2008). Unlike line intercept sampling, objects are recorded on either side of the line according to some rule of inclusion. When a total count of objects is attempted within a fixed distance of the line, transect sampling is analogous to sampling on a fixed plot. This form of line transect, also known as a belt (strip) transect, has been used by the US Fish and Wildlife Service (USFWS) (Conroy et al. 1988) in aerial counts of black ducks. As with most attempts at total counts, belt transect surveys usually do not detect 100% of the animals or other objects within the strip. When surveys are completed according to a standard protocol, the counts can be considered an index. Conroy et al. (1988) recognized ducks were missed and suggested that survey results should be considered an index to population size.

Line-transect sampling wherein the counts are considered incomplete has been widely applied for estimation of density of animal populations. Burnham et al. (1980) comprehensively reviewed the theory and applications of this form of line transect sampling. Buckland et al. (1993) updated the developments in line transect sampling through the decade of the 1980s. Alpizar-Jara and Pollock (1996), Beavers and Ramsey (1998), Manly et al. (1996), Quang and Becker (1996, 1997), and Southwell (1994) developed additional theory and application. The notation in this section follows Burnham et al. (1980).

There are several assumptions required in the use of line transect surveys (Buckland et al. 2001), including:

1. Objects on the line are detected with 100% probability.
2. Objects do not move in response to the observer before detection (e.g., animal movements are independent of observers).
3. Objects are not counted twice.
4. Objects are fixed at the point of initial detection.
5. Distances are measured without errors.
6. Transect lines are probabilistically located in the study area.

The probability of detecting an object at a perpendicular distance (the detection function) of $x$ from the transect line is used in correcting for visibility bias away from the line of counted objects (Morrison et al. 2008). Detection functions can be made up of a mixture of more simple functions which depend on factors such as weather, observer training, vegetation type, etc., so long as all such functions satisfy the condition that probability of detection is 100% at the origin $x = 0$ (Burnham et al. 1980). The field of abundance and density estimation from transect-based sampling schemes is active, so additional methodologies are sure to be forthcoming (Morrison et al. 2008). Counting of organisms along a transect is a useful sampling procedure when the organisms of interest are relatively rare. For example, line transect sampling is frequently used in estimation of abundance of grassland birds (see Shaffer and Johnson 2009).

***Variable area circular plots.*** The variable circular plot often is applied as a variation of line-transect sampling. The variable circular plot is recommended for surveys of organisms in dense vegetation and rough terrain where attention may be diverted from the survey and toward simply negotiating the transect line. An added advantage of the circular plot is that the observer can allow the surveyed animals to settle down. For example, in estimating the number of birds in an area (Reynolds et al. 1980) in breeding bird surveys, observers wait several minutes to allow the songbirds disturbed by their arrival to settle down before visual and auditory counts begin.

This technique also is useful when the objective is to relate animals within a circular area to characteristics (e.g., vegetation) of the area.

Although the plot is referred to as circular, the procedure is shapeless as all observations made from a point, in any direction, are recorded. Plot size is a function of the observer's ability to detect the organism of interest and not the design (Ramsey and Scott 1979). As with a line transect, estimation of the number of organisms within the area surveyed is based on a detection function that represents the distance at which the observer can detect organisms of interest.

Program DISTANCE (Buckland et al. 1993, 2001) is frequently used to estimate animal densities from variable circular plot data. The theoretical models and estimation methods used in DISTANCE work best when at least 40 independent observations exist for the area of interest (Morrison et al. 2008). Data may be pooled across time periods or species to estimate detection functions resulting in an average detection probability.

The assumption that counts are independent may be difficult, as subjects being counted are seldom marked or obviously unique. Biologists may consider estimating use per unit area per unit time as an index to abundance. When subjects are relatively uncommon, the amount of time spent within distance intervals can be recorded. In areas with a relatively high density of subjects, surveys can be conducted as instantaneous counts of animals at predetermined intervals of time during survey periods (Morrison et al. 2008).

***Spatial statistics.*** Wildlife studies frequently are interested in describing the spatial pattern of wildlife resources in relation to environmental parameters. Manly (2009) provides a summary of spatial data analysis and includes the following uses:

1. Detect patterns in the locations of objects in space.
2. Quantify correlations between the spatial locations for two types of objects.
3. Measure the spatial autocorrelation for the values of a variable measured over space.
4. Study the correlation between two variables measured over space when one or both of those variables displays autocorrelation.

In a study using spatial statistics, data generally are gathered from a grid of points and the spatial covariance structure of variables is used to estimate the variable of interest at points not sampled (Morrison et al. 2008). The data on the variable of interest at the sample locations could be used to predict the distribution of the variable for management or conservation purposes. For example, bird counts as an index of local use could be used to design the wind facility to avoid high bird use areas (e.g., Foote Creek Rim report; Johnson et al. 2000).

## DATA ANALYSIS

### Univariate Analyses

The analysis of impact assessment studies may be complicated because they usually involve repeated measurements over time at study sites (Stewart-Oaten and Bence 2001) and repeated measures at one site often will be correlated (Manly 2009). If such correlation is not taken into account in the analysis of data, then the design has pseudoreplication, potentially over-estimating the statistical significance of the impact (Manly 2009). When there are multiple control and impact sites, Manly (2009) suggested the use of a repeated-measures analysis of variance. There are other potential methods of analysis of data for several control and impact sites; these methods can become quite complicated, and expert advice should be sought.

It is assumed that quantification of impact will be based on measurements for indicators that satisfy the criteria for determination of impact and that multiple reference and impact areas will not be available. For these indicators in this circumstance, conducting a series of independent univariate analyses is recommended. For example, the number of dead birds found per square kilometer ($km^2$) of wind facility surveyed following a year of operation might be estimated and compared to the number of dead individuals found per $km^2$ on a reference area. During the same year of the same study, the number of fledglings produced per nest might be estimated and compared among the study areas.

It is recommended that impact and recovery of a biological community be defined in terms of individual impact indicators. Examples of impact indicators include the number of individuals of a particular species, biomass of a particular species, and number of species present. Impact is determined by evaluating differences between impact indicators before and after an impact on the assessment area (BA designs) or the assessment and reference areas (e.g., BACI designs). An impact-gradient design looks for a trend in the values of impact indicators with increasing distance from a point source impact (Manly 2009). Recovery is considered incomplete and an impact exists in the biological community as long as any differences (positive or negative) in indicators can be detected between assessment and reference areas within the particular study design used (Page et al. 1993; Stekoll et al. 1993; Manly 2009). It is also recommended that:

- The biological community be characterized in terms of relatively uncorrelated indicators that are impact indicators; and that
- Individual tests of direct and more understandable measures of community response be used rather than the multivariate indices mentioned below.

As an example, several comparisons of impact indicators – e.g., the numbers of several species and the biomass of those same species – are made between a wind facility and reference areas. The species selected should be relatively unrelated ecologically (e.g. golden eagles and several species of passerines and shore birds). In the analysis of impact the percentage of biological indicators that are significantly different (positive or negative) when tested at a given level of significance (Page et al. 1993; Stekoll et al. 1993) is used to determine the direction and magnitude of the impact. This use of a relatively large number of individual comparisons is related to the *vote-counting method* of meta-analysis (Hedges and Olkin 1985; Hedges 1986).

In spite of the recommendation above that indicators be uncorrelated, the indicators (e.g. number of individuals of a species) will always be correlated to a certain extent. Thus, individual comparisons used in determining impact (i.e., the *P*-values from the indicators) are not independent. Admittedly the procedure is *ad hoc* if applied only once after the impact, because the expected percentage of significant differences is unknown (under the hypothesis that assessment and reference areas have the same distributions for indicators). However, impact to the community can be inferred if, for example:

- In a BACI design (with data collected before and following the impact) there is an abrupt increase in the percentage of significant differences following the incident (the inference will be more reliable if the abrupt increase is followed by a return to baseline levels, i.e., recovery); or,

- In an Impact-Reference design (with several time periods of data collected following the impact) there is a large percentage of significant differences relative to the size of the test (e.g., $\alpha = 0.05$) immediately following the impact which is followed by a reduction in the percentage (the inference will be more reliable if the percentage decreases to about 5%).

This form of data analysis increases the likelihood of Type I errors (described under "Statistical Power and Weight of Evidence," below) and makes the interpretation of results in studies with a large number of impact indicators difficult. The assessment of the statistical significance of differences is also more subjective than with multivariate tests, placing a greater burden on the researcher in evaluating the results. However, univariate tests help interpret results in terms of biological significance. As mentioned above, some correlation among impact indicators usually will exist and univariate analyses will help with the interpretation of the significance of this correlation in the determination of impact. In the univariate analysis the detection of obvious impacts and their cause will be more straightforward and more easily defended when compared to multivariate indices of impact.

### Multivariate Analysis

There is a great deal of interest in simultaneous analysis of multiple indicators (*multivariate analysis*) to explain complex relationships among many different kinds of indicators over space and time. This is particularly important in studying the impact of a perturbation on the species composition and community structure of flora and fauna (Page et al. 1993; Stekoll et al. 1993). These multivariate techniques (Gordon 1981; Green 1984; James and McCulloch 1990; Ludwig and Reynolds 1988; Manly 1986, 2009; Pielou 1984; Seber 1984) include multidimensional scaling and ordination analysis by methods such as *principal component analysis* and *detrended canonical correspondence analysis* (Page et al. 1993). If sampling units are selected with equal probability by simple random sampling or by systematic sampling from the assessment and reference areas, and no pseudo-experimental design is involved (e.g., no pairing), then the multivariate procedures are applicable.

It is unlikely that multivariate techniques will directly yield impact indicators (i.e., combinations of the original indicators) that meet the criteria for determination of impact. The techniques certainly can help explain and corroborate impact if analyzed properly within the study design. However, data from many recommended study designs are not easily analyzed by those multivariate indices, because, for example:

- In stratified random sampling, units from different strata are selected with unequal weights (unequal probability).
- In matched pair designs, the inherent precision created by the pairing is lost if that pair bond is broken.

### Meta-Analysis

*Meta-analysis* is a relatively new approach as applied to the analysis of ecological field studies. It involves the combination of statistical results from several independent studies that all deal with the same issue (Hedges and Olkin 1985; Hedges 1986). While many biologists and statisticians are unfamiliar with its application, meta-analysis has been well known and widely used in some fields (e.g. psychology, medical research) for quite some time. It may be extremely important for use of historical and baseline data in impact assessment. The simplest form of meta-analysis (Fisher 1970) is easy to understand. If several independent statistical comparisons are made on the same impact indicator but with relatively low sampling intensity, then it is possible that none are significant at the traditional level of $P \leq 0.05$. However, all or most significance levels may be "small" (e.g., all Ps are $\leq 0.15$) and suggestive of the same type of impact. The probability that, for example, three or more independent tests would, by chance, indicate the same adverse impact if there were no actual impact from the perturbation, is itself an unlikely event. The combined results may establish impact due to the incident with overall significance level $P \leq 0.05$.

For a second illustration, historic scientific studies in a given assessment area may have addressed the same basic objective, but were conducted by different protocols with varying degrees of precision. It is difficult to combine original data from such studies, but it may be possible to combine results of statistical tests using meta-analysis to establish a reliable measure of baseline conditions.

For a third illustration of potential use of meta-analysis, consider stratified random sampling, where sampling intensity within a given stratum (e.g., vegetation type) is not sufficient to reject the classical null hypothesis of "no impact." If the point estimates of effect are in the same direction and indicate impact, then the statistical results might be combined across strata (e.g., vegetation type) by meta-analysis to establish the overall conclusion of impact at an acceptable level of precision.

An alternative form of meta-analysis used in medical research is the statistical analysis of pooled data from numerous independent studies. This approach is only appropriate when methods and metrics are similar among the studies included in the analysis (Morrison et al. 2008). Erickson et al. (2002) illustrated the use of meta-analysis of pooled data from a relatively large group of independent observation studies of the impacts of wind energy facilities on birds and bats. The study analyzed data on mortality, avian use, and raptor nesting for the purpose of predicting impacts based on various levels of effort. The authors carefully screened the methods used in the independent studies to insure that pooling was appropriate.

Discussion of all aspects of the emerging field of meta-analysis is beyond the scope of this document (see, for example, Hedges and Olkin 1985; Hedges 1986; Durlak and Lipsey 1991; Draper et al. 1992; Burnham 1995; Hunter and Schmidt 1990: see reviews by Arnqvist and Wooster 1995; Gurevitch et al. 2001; Gates 2002). Meta-analysis should be considered if several historic or baseline studies have been conducted. It may also be of value if several independent studies point in the same direction of impact, but individually lack the usual scientific requirements for statistical inferences that the impacts are "real."

**Resource Selection**

As well summarized elsewhere (e.g., Manly et al. 2002; Morrison et al. 2006), documentation of the resources used by animals is a cornerstone – along with quantifying distribution and abundance – of animal ecology. Thus, much literature is available on how to identify, quantify, and interpret the use of resources by animals (Morrison et al. 2008). Scientists often identify resources used by animals (e.g. vegetation type, food) and document their availability (usually expressed as abundance or presence/absence). Usually these studies are carried out to identify the long-term requirements for the management or conservation of an animal population. The amount of a resource in the environment that is accessible to an animal is termed *resource availability*; whereas, the absolute amount of that resource in the environment is termed *resource abundance*. *Resource selection* is defined by Manly et al. (2002) as the use of a resource relative to the availability or abundance of that resource.

Resource selection can be analyzed by comparing two of the three possible sets of resource units, namely used, unused, and available. Manley et al. (2002:5-6) used these sets to identify three common sampling protocols:

A. Available units are either randomly sampled or censused and used resource units are randomly sampled.
B. Available resource units are either randomly sampled or censused and a random sample of unused units is taken.
C. Unused resource units and used resource units are independently sampled.

Three general study designs for evaluating resource selection have been identified in the literature (see especially Thomas and Taylor 1990). Each of the above three sampling protocols (A, B, C) can be used for each of the following study designs, and the specific combination of protocol and design used to gather the data determines some of the underlying assumptions required for subsequent analyses (Morrison et al. 2008).

<u>Design 1:</u> The availability and use for all items are estimated for all animals (population), but organisms are not individually identified, and only the item used is identified. Availability is assumed to be equal for all individuals. Habitat studies often compare the relative number of animals or their sign of presence in each vegetation type to the proportion of that type in the study area.

<u>Design 2:</u> Individual animals are identified, and the use of each item is estimated for each animal. As for Design 1, availabilities are assumed equal for all individuals and are measured or estimated for the entire study area. Studies that compare the relative number of relocations of marked animals in each vegetation type to the proportion of that type in the area fall into this category.

<u>Design 3:</u> This design is the same as Design 2, except that the availability of the items is also estimated for each individual animal. Studies in this category often estimate the home range or territory for an individual and compare use and availabilities of items within that area.

Thomas and Taylor (1990) and Manly et al. (2002) provided a good review of studies that fit each of these categories, as well as guidelines for sample sizes necessary to conduct such analyses. Studies using Design 1 tend to be inexpensive relative to Designs 2 and 3 because animals do not need to be identified individually. Designs 2 and 3 allow for analysis of resource selection on the individual, thus estimates calculated from observations may be used to estimate parameters for the population of animals and produce estimates of variability of these estimates (Morrison et al. 2008).

The differential selection of resources provides information about the ecology of birds, bats and other wildlife that should also improve the assessment of risk posed by potential wind facilities. Resource selection also could be used in model-based analyses of such things as the difference in mortality associated with turbine design. The specific statistical procedures and models used in resource selection studies are basically the same as those used in other studies of wildlife ecology, and have been well presented by Manley et al. (2002). Using most of the designs previously discussed, resource selection models can be used to evaluate mortality and other metrics indicating risk to wildlife as a function of distance to various turbine types.

Resource selection is conceptualized to occur as a hierarchical, decision making process by an animal (e.g., Manly et al. 2002:1-2; Morrison et al. 2006:155-158). Thus, when designing a study of resource selection you must consider how the animal and resources interact across spatial scales, from the broad (landscape) to the local (e.g., feeding site). In many cases studies must be designed to account for multiple scales of selection. Additionally, resource selection will vary by season, and sex and age class (Morrison et al. 2008).

Statistical tools used in habitat selection studies are applied to the animal use data for investigation of habitat selection as well as the effects of the turbines on the wildlife resource. Data collected prior to development of the wind facility can be used to determine what important factors appear to be related to presence/absence of an animal species or the magnitude of use by the species. For example, through multiple regression techniques it may be shown that use by a species of bird is related to the amount (percentage of area) of land protected under the Conservation Reserve Program (CRP) within the vicinity of the point-count or to distance from the nearest wetland. Using presence/absence data at the point-count location, logistic regression (Hosmer and Lemeshow 1989) can be used to estimate the relative probability that an area will be used as a function of the characteristics of the area. For example, it may be shown that distance to the nearest wetland is related to the probability of use for a species, and those areas at (for example) 300 meters are twice as likely to have bird use by this species as areas at 500 meters. These functions may be useful in developing a data layer in a GIS system indicating those regions within a development which have the highest probability of use by the given species. This information may be useful in siting turbines in future phases.

Resource selection techniques can be applied to evaluate effects of wind turbines on animals. For example, logistic regression models may show that a bird species has a higher probability of using an area that is far from turbines (i.e., possible avoidance of turbines). Multiple regression models may be used to determine if distance to turbines is negatively related to the magnitude of bird use.

Data collected at the point (e.g., bird use, presence/absence, and habitat) are used in the logistic and multiple regression analyses. Because repeated correlated measures are made of these variables at the point, bootstrapping techniques (Manly 1991; Ward et al. 1996) can be used to estimate the precision and confidence in the coefficients of the regression analyses and to avoid pseudoreplication.

In most field studies it will be impossible to identify unique animals. However, by using observations of animals seen from randomly or systematically chosen points it is possible to use resource variables with known availability (e.g., vegetation) as predictor variables (Design 1 from above). For example, if it appears that a certain vegetation type is preferentially selected for hunting by red-tailed hawks within 0.5 km of a nest, then one could predict that the risk of impact would increase if turbines were constructed on preferred hunting habitat <0.5 km from a nest. Alternatively, the study area could be classified into available units characterized on the basis of a set of predictor variables such as vegetation type, distance to water, distance to a nest, and distance to a turbine. The presence or absence of use of a sample of units could then be used to assess the effect of the predictor variables on bird use. In the case where study plots are searched for the presence or absence of dead birds or bats, resource selection could be used to evaluate the effect of a set of predictor variables on mortality.

Radio telemetry offers a unique opportunity to use resource selection in the study of the impacts of wind facilities on habitat use by wildlife, particularly prairie grouse (Design 2 or 3 from above). For example, research into the response of prairie chickens to wind energy development is being conducted at the Meridian Way Wind Farm in the Smoky Hills of Cloud County in eastern Kansas. The study included pre- and post-construction data on land where wind energy projects are proposed and on control sites where development is not planned; the experimental and control sites are currently undisturbed prairie rangeland. This venture is a collaborative scientific inquiry to establish whether there are effects from wind structures to prairie chickens in the Midwest (Brett Sandercok, Kansas State University, personal communication). Based on the results of this pre-treatment data, the areas were spatially classified from high to low probability of use. Once the wind facility is constructed, spatial changes in the probability of use in response to development will be estimated. Sawyer et al (2006) provides an excellent example of this type of impact assessment in his study of the impacts of gas development on mule deer in western Wyoming.

**Statistical Power and the Weight of Evidence**

Scientists often are concerned with the statistical power of an experiment, that is, the probability of rejecting a null hypothesis when it is false. Four inter-related factors determine statistical power: power increases as sample size, α-level, and effect size increase; power decreases as variance increases. Understanding statistical power requires an understanding of Type I and Type II error, and the relationship of these errors to null and alternative hypotheses. It is important to understand the concept of power when designing a research project, primarily because such understanding grounds decisions about how to design the project, including methods for data collection, the sampling plan, and sample size. To calculate power the researcher must have established a hypothesis to test, understand the expected variability in the data to be collected, decide on an acceptable α-level, and most importantly, decide on a biologically relevant response level (Morrison et al. 2008).

Traditionally in scientific research, a null hypothesis – that there is no difference in the value of an indicator between reference areas and assessment areas or that there is a zero correlation between two indicators along their gradients – is adopted as the “straw man” that must be rejected in order to infer that an indicator has changed or that a cause-and-effect relationship exists. Although this approach has pervaded the scientific method and discipline of statistics for nearly a century, it usually places the burden of scientific proof of impact on regulators. The classical use of a null hypothesis protects only against the probability of a Type I Error (concluding that impact exists when it really does not, i.e., a false positive). Often the significance level is required to be below $\alpha = 0.05$ before the conclusion of impact is considered to be valid. The probability of a Type II Error (concluding no impact when in fact impact does exist, i.e., a false negative) is commonly ignored and is often much larger than 0.05. The risk of a Type II error can be decreased by conducting larger, more expensive studies or, in some situations, through use of better experimental design or more powerful types of analysis. In general, the power of a statistical test of some hypothesis is the probability that it rejects the null hypothesis when it is false. An experiment is said to be very powerful if the probability of a Type II Error is very small.

The traditional statistical paradigm is geared to protect against a “false positive,” but the interest of the regulator is protection against a “false negative.” A more fair statistical method is needed to balance protection against the two possible errors. The standard paradigm is clumsy at best and is not easily understood by many segments of society. For discussion of an alternative paradigm, see McDonald (1995), McDonald and Erickson (1994), and Erickson and McDonald (1995).

In the case of wind facility monitoring, the null hypothesis will usually be that there is no impact to one or more wildlife species or their habitat. Accepting a “no impact” result when an experiment has low statistical power may give regulators and the public a false sense of security. The power of the test to detect an effect is a function of the sample size, the chosen $\alpha$ value, estimates of variance, and the magnitude of the effect. The $\alpha$ level of the experiment is usually set by convention, if not by regulation, and the magnitude of the effect in an observational study is certainly not controllable. Thus, sample size and estimates of variance usually determine the power of observational studies. Many of the methods discussed in this appendix are directed toward reducing variance in observational studies. When observational studies are designed properly, the ultimate determination of statistical power is sample size.

The lack of sufficient sample size necessary to have reasonable power to detect differences between treatment and reference areas is a common problem in field studies described in this chapter. Estimates of direct mortality can be made in a given year through carcass searches, but tests of other parameters for any given year (e.g., avoidance of wind facility by bird species) may have relatively little power to detect an effect of wind energy development on the species of concern. The lack of power is a concern and should be addressed by increasing sample size, through the use of other methods of efficient study design described above, and by minimizing measurement error (e.g., through use of the proper study methods, properly trained personnel, etc.). However, most field studies will result in data that must be analyzed with an emphasis on detection of biological significance when statistical significance is marginal. Computer-intensive methods allow estimates of variance and standard error when complicated designs make standard estimates of variance problematic (Manly 1991). Such methods can be useful in calculating confidence intervals and in tests of hypotheses using data with non-standard distributions. Computer-intensive methods also can be used with pilot data to predict necessary sample sizes to meet objectives for precision. For a more complete study of statistical power see Cohen (1973), Dallal (1992), Fairweather (1991), Peterman (1989), and Morrison et al. (2008).

The trend of differences between reference and impact areas for several important variables may detect impacts, even when tests of statistical significance on individual variables have marginal confidence. This deductive, model-based approach is illustrated by the following discussion. The evaluation of effects from wind energy development includes effects on individual animals (e.g., reduction or increase in use of the area occupied by the turbines) and population effects such as mortality (e.g., death due to collision with a turbine). Several outcomes are possible from the wildlife studies. For example, a decline in bird use on a new wind facility without a similar decline on the reference area(s) may be interpreted as evidence of an effect of wind energy development on individual birds. The presence of a greater number of carcasses of the same species near turbines than in the reference plots increases the weight of evidence that an effect can be attributed to the wind facility. However, a decline in use of both the reference and development area (i.e., an area with wind turbines) in the absence of large numbers of carcasses may be interpreted as a response unrelated to the wind facility. Data on covariates (e.g., prey) for the assessment and reference area(s) could be used to clarify this interpretation further.

The point at which fatalities are considered significant is subjective and will depend on the species involved. Even a small number of carcasses of a rare species associated with turbine strings may be considered significant, particularly during the breeding season. A substantial number of carcasses associated with a decline in use relative to the reference area, particularly late in the breeding season during the dispersal of young, may be interpreted as a possible population effect. The suggestion of a population effect may lead to additional post-construction studies.

***Sampling intensity.*** Usually the largest source of variation in impact indicators is natural variation among sampling units across study areas and time, not measurement and subsampling error (e.g., determining the cause of death through blind necropsy). Precision of statistical procedures and power to detect important changes in impact indicators usually will be most influenced by an increase in the number of independent sampling units in the assessment and reference areas. A rule of thumb for improving statistical precision is to increase the number of independent field sampling units. If preliminary or pilot data are available, optimal allocation of financial resources to increase precision in statistical procedures (i.e., stratification) should be considered.

## SUMMARY AND CONCLUSION

Protocols for wildlife studies will, by necessity, be site- and species-specific. However, all protocols should follow good scientific methods. Many of the issues related to wildlife impacts of wind energy development are contentious, and settling these issues will be assisted by good scientific studies. However, many of the issues related to wind energy impacts on wildlife are based on relatively rare events. First, producing electricity commercially with wind energy is a relatively recent development. Bird fatalities appear to be infrequent in most wind facilities. Many of the bird species of major concern also are rare. Bat fatalities also are relatively rare, although fatalities at several sites in the east and mid-west have been relatively numerous (Kunz et al. 2007b). An additional complication with bats is the difficulty of determining the number of bats that are exposed to collisions with wind turbines. Second, as pointed out in this chapter, the construction of a wind facility is not a random occurrence and potential wind facility sites are relatively unique, making selection of reference areas difficult. In spite of these difficulties, bird and bat mortality and habitat impacts for all wildlife are a significant concern and wind energy is a potential clean source of electricity, making study of these issues essential.

Because impact indicators normally are estimates of relatively rare events, analysis of impacts must rely on an accumulation of information and rigorous study designs. A determination of impact seldom will be based on clear-cut statistical tests, but usually will be based on the weight of evidence developed from the study of numerous impact indicators, over numerous years, at numerous wind facilities. The selection of the appropriate protocol must be site- and species-specific. Protocol selection will be influenced by the status of the wind energy project (existing or proposed), the area of interest, the issues and species of concern, cooperation of landowners, and so on. Decisions about methods, designs, and sample sizes will always be influenced by budget considerations.

The following is a summary of important considerations when designing observational studies:

1. Clearly define the objectives of the study including the questions to be answered, as well as the area, the species, and the time period of interest.

2. Clearly define the area of inference, the experimental unit (and sample size), and the sampling unit (and subsample size).
3. Clearly define the parameters to measure, select impact indicators which are relatively uncorrelated to each other, measure as many relevant covariates as possible, and identify obvious biases. Impact indicators should allow for the determination of impact following generally accepted scientific principles and as defined by the standards agreed to by stakeholders.
4. The BACI design using multiple treatment and control sites is the most reliable design for sustaining confidence in scientific conclusions based on observational studies. Data should be collected for two or more time periods before and again two or more time periods after construction of the wind facility on both the assessment area (wind facility) and multiple reference areas. Consider matching pairs of sampling units (data collection sites) within each study area based on matching criteria which are relatively permanent features (e.g. topography, geology). If the BACI design cannot be implemented, then other appropriate designs should be used.
5. Use a probability sampling plan, stratify on relatively permanent features, such as topography, and only for short-term studies; use a systematic sampling plan for long-term studies, spread sampling effort throughout area and time periods of interest, and maximize sample size.
6. Develop detailed standard operating procedures (SOPs) prior to the initiation of fieldwork and select methods that minimize bias.
7. Make maximum use of existing data and consider some preliminary data collection where little information exists.
8. When pre-construction data are unavailable then combine data collection on multiple reference areas with other study designs such as the gradient-response design.
9. Maximize sample size within budgetary constraints.
10. Univariate analysis is preferred, especially when determining impacts by a weight of evidence approach.
11. Study plans should be peer-reviewed.

Each wind energy project will be unique, and decisions regarding the study design, sampling plan, and parameters to measure will require considerable expertise. There is no single combination of study components appropriate for all situations. However, at the risk of oversimplification, Table 1 contains a simple decision matrix to assist in the design of wind energy/wildlife interaction studies.

Studies should detect major sources of impact on species of interest and assist in the design of wind energy projects to reduce impacts on wildlife. When there is uncertainty on wildlife risk studies should also identify sites where there is a low probability of risk to these species. More often than not, the product of these studies will be to focus future research on areas where significant biological impacts appear likely, or to identify that no further research is needed.

**Table 1. Recommended decision matrix for the design and conduct of observational studies.**

| (a) Design Options | | | |
|---|---|---|---|
| **Study Conditions** | **Recommended Design** | **Potential Design Modification** | |
| Pre-impact Data Possible Reference Area Indicated | BACI | Matching of study sites on assessment and reference areas possible | Matched Pair Design With BACI |
| Pre-impact Data Not Possible Reference Area Indicated | Impact-Reference | Matching of study sites on assessment and reference areas possible | Matched Pair Design With Impact-Reference |
| Pre-impact Data Possible Reference Area Not Indicated | Before-After | | |
| Small Homogenous Area of Potential Impact | Impact-Gradient[1] | | |

| (b) Sampling Plan Options | |
|---|---|
| **Sampling Plan** | **Recommended Use** |
| Haphazard/Judgment Sampling | Preliminary Reconnaissance |
| Probability-Based Sampling | |
| Simple Random Sampling | Homogenous area with respect to impact indicators and covariates |
| Stratified Random Sampling | Strata well defined and relatively permanent, and study of short duration |
| Systematic Sampling | Heterogeneous area with respect to impact indicators and covariates, and study of long duration |

| (c) Parameters To Measure | |
|---|---|
| **Parameter** | **Empirical Description** |
| Abundance/Relative Use | Use per unit area or per unit time as an index[2] |
| Mortality | Carcasses per unit area or per unit time |
| Reproduction | Young per breeding pair of adults |
| Habitat Use | Use as a function of availability |
| Covariates | Vegetation, topography, structure, distance, species, weather, season, etc. |

[1]Impact-Gradient design can be used in conjunction with BACI, Impact Reference, and Before-After designs.

[2]Can be summarized by activity/behavior for evaluation of risk.

## EXPERIMENTS

In the case of wind energy, manipulative experiments (also known as “comparative experiments” [Cox 1958; Kempthorne 1966] and “randomized experiments” [NRC 1985]) usually will be conducted to evaluate risk reduction management options for existing and new wind facilities. For example, turbine characteristics such as support structure type, rotor swept area, and turbine color have been suggested as factors affecting bird risk in wind facilities (NRC 2007). Observational studies, such as Anderson et al. (1996) can be used to evaluate some of these risk factors. However, manipulative experiments could significantly improve the understanding of how these factors relate to the risk of bird and bat collisions with turbines. Manipulative experiments help determine treatment effects by allowing control of such factors as natural environmental variation, which tend to confound observational studies.

The main goal of this discussion is to develop a framework for more complex studies that can be generalized to most wildlife species for evaluation of potential wind facility impacts. This is accomplished by:

- Developing a conceptual framework based on the major factors that can influence the persistence of a wild population.
- Briefly reviewing the basic approach to manipulative experiments as well as the various models that can aid in estimating population status and trend, including methods of evaluating model structure and performance.
- Reviewing survivorship and population projections.
- Developing a framework for determining the cumulative effects of wind energy development on wildlife.

This chapter does not argue against rigorous design-based (field) studies. Rather, it describes how an alternative, model-based approach can assist with evaluation of wind energy/wildlife interaction issues. Before proceeding to a detailed discussion of population effects and modeling, a brief discussion of manipulative experiments is offered.

**Manipulative Experiments**

Manipulative experiments may be useful in wind energy/wildlife interaction studies. They satisfy two criteria:

1. Two or more "treatments" (one of which usually is a control, or reference treatment) are to be compared for study of cause-and-effect relationships on impact indicators.
2. Treatments are randomly assigned to experimental units (Hurlbert 1984).

If treatments are not randomly assigned to experimental units, the experimental design becomes observational, and the information gained on cause-and-effect relationships is much reduced (Cox 1958; Kempthorne 1966; Morrison et al. 2008; Manly 2009). Designs for studying impacts of a wind facility can never be *truly* manipulative, because the area/population to be impacted by the facility and the reference areas/populations are not randomly selected by the researcher.

In manipulative experiments the statistical inference is still the protocol by which the study is conducted, the criteria by which study sites are selected, the source of the treatment materials, and the amount of replication in time and space. For example, if two wind facilities are selected for the study of some treatment and the treatment and references are randomly assigned within the two facilities, there exist two independent studies. Statistical inference is limited to the effect of the selected treatment as applied in the study on the wind facility where it is applied for the time period of application. The results of the two independent studies can be used in the subjective assessment of the potential effect of the treatment on other wind facilities.

Any design used in laboratory experiments or manipulative field experiments are of use in studies of wind energy/wildlife interactions, and a complete discussion of these options is beyond the scope of this document. For details on study design see references such as Cox (1958), Box et al. (1978), Green (1979), Hurlbert (1984), Morrison et al. (2008), and Manly (2009). All of the design principles and the basic sampling designs contained in the discussion of observational studies are appropriate for manipulative experiments. However, it is worth repeating Krebs (1989) that "every manipulative ecological field experiment must have a contemporaneous control..., randomize where possible..., and, because of the need for replication, utilize at least two controls and two experimental areas or units."

The following example illustrates the use of common design principles in the evaluation of a hypothetical risk reduction treatment included in the design of a newly constructed wind facility. This is just one example from among an almost infinite number of potential designs. Suppose a new wind facility is constructed consisting of 120 turbines distributed in 12 turbine strings, each with 10 turbines. Also suppose a two-year study is conducted to evaluate a treatment applied to some of the turbines hypothesized to reduce the risk of bird collisions with turbines. Finally, assume that risk is measured by the relative amount of bird use and bird carcasses located within study plots centered on treated and untreated turbines.

In year one of the study, avian use and mortality are measured on plots containing turbines without treatment; in year two, use and mortality are measured on plots containing turbines both with and without the selected treatment. All twelve turbine strings are surveyed for avian use, behavior, and mortality, so a census in space within the wind facility is achieved. It is assumed that if a bird comes into the defined critical zone surrounding the turbines (some distance from turbines), then the bird is potentially at risk of injury. If the bird does not enter the critical zone, it is assumed that the bird is not at risk of injury. Risk is thus defined as use within a certain distance of a turbine. Fatalities are measured and an estimate is made of mortality per unit of use. Risk also may be defined as a change in mortality per unit of use.

There are two basic paradigms regarding the analysis of these data. One paradigm is that the sampling design is a matched pairs design (randomized block with two treatment levels). The second paradigm is that this is a manipulative study embedded in a large observational study using a BACI design. In the first paradigm, the effectiveness of the treatment is evaluated by testing the interaction between year and treatment. A two-factor repeated measures analysis of variance is conducted using the mortality rate (number of carcasses per search divided by bird use per visit per observation point) as the dependent variable. Figure 5 illustrates the mean mortality per unit of bird use near turbines by year and treatment. There appears to be an interaction between year and treatment; the mean is relatively stable for the non-treated turbines, whereas the mean for the treated turbines decreases in year 2. Given that a statistical test for interaction corroborates our interpretation of the graph, statistical tests of treatment effects should be conducted within each year. Bird fatality near treated turbines is significantly less than near the non-treated turbines in year 2, indicating that the treatment does appear to reduce the risk to birds.

The second paradigm recognizes that the turbines (and turbine strings) are not random effects because the wind facility, turbine strings, and turbines are not randomly located. According to this paradigm, this is a pseudo-experiment with an unreplicated observational study over time and space. The analysis would follow statistical analyses for BACI designs (Skalski and Robson 1992).

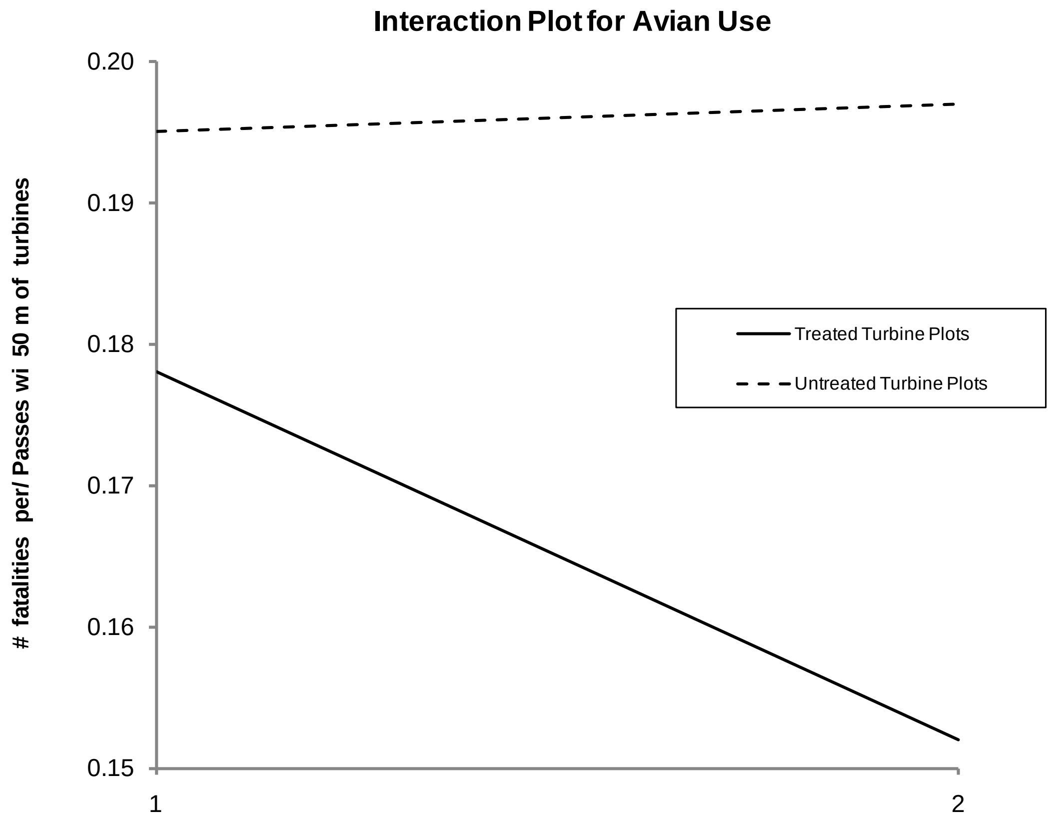


**Figure 5. Interaction between the number of fatalities per bird passes within 50 meters of treated and untreated turbines.**

In the above example, the design could be modified by applying the treatment and reference in year one to the selected subset of turbines and switching the treatment and reference turbines the second year. While this design slightly strengthens the study, it would be practical only if the risk reduction treatment were relatively easy and inexpensive to apply.

Manipulative studies can be very complex. However, because of the cost of treating wind turbines, most studies will by necessity be limited to simple designs evaluating a small number of treatments. Manipulative studies will be most valuable initially in evaluating treatments on individual wind facilities. As data accumulate, subjective inference on a more global scale will be possible. However, care must be taken to avoid extrapolating the effectiveness of a treatment at one or a few wind facilities to all wind facilities.

## RECOMMENDATIONS FOR STUDY DESIGN

Below is a summary of the primary points discussed in this appendix:

1. ***Manipulative studies*** can be an effective means of determining the response of wildlife to treatments or experiments designed to test behavior, such as procedures designed to identify methods for reducing the risk of animal deaths.
2. Developing a ***sound modeling framework*** may help identify the critical aspects of the population that should be studied, even if a formal model is not calculated.
3. In many situations, ***quantification of survivorship*** is an essential step in determining the status of the population of interest. Data on survival published in the literature is adequate to allow broad generalizations to be made regarding “adequate” survival for population maintenance.
4. Determining the ***spatial structure of a population*** – whether it is divided into subpopulations – is important in that it places the status of various life history parameters into context.
5. ***Quantifying reproductive output and breeding density***, when combined with knowledge of the population’s spatial structure, provides a good idea of the status of the population. This will be especially important when adult survivorship cannot easily be determined.
6. Habitat loss is usually a factor causing the decline of a species. ***Quantification of habitat use***, including factors such as food abundance, can be an important part of evaluation of a population’s status.
7. ***Compensatory mortality*** should not be assumed to be operating with regard to wind facility-related mortalities.
8. It is likely that ***Leslie matrix models*** will be most useful when predicting the response of locally abundant subpopulations. Here, enough individuals are present for a population trend to be estimated.
9. Determination of the ***effective population size*** (*Ne*) likely will be useful in evaluating the status of rare subpopulations. A rapid determination of the likely lower critical threshold for the subpopulation is necessary.

### Measuring Risk

*Potential Observational Data*

There are a limited number of parameters that can be measured during observational studies. These studies normally will not use marked animals and the observational methods will not allow estimation of absolute abundance. However, observational data can be used to estimate use, which can be considered an index to abundance, where the parameter measured is an observation of an individual animal over some specific time period. Individual behaviors also can be quantified. Observations of use can be classified according to activity, and thus used to estimate the amount of time a particular species spends perching, soaring, flapping, and performing other activities. If these activities can be related to risk, they can be used to test hypotheses regarding the impact of wind facilities on animals. For example, it may be assumed that the more time a species spends flying at heights encompassed by the rotor swept area of turbines, the more risk the species faces in a wind facility. Measures of use should allow a comparison of potential wind facility sites for differences in risk to bird species. The season of use can indicate the relative abundance of migrants, wintering birds, and breeding populations.

Because many birds migrate at night and bats are primarily active at night, estimates of nocturnal use are of interest, but suitable methods are still in the developmental stage (Kunz et al. 2007b; Appendix A). The use of these methods in the study of wind energy development and its impacts on nocturnally active wildlife is summarized in detail in Kunz et al. (2007a; Appendix A).

Remote sensing methods (e.g., radar, acoustics) for bird and bat studies related to wind energy development are thoroughly described by Kunz et al. (2007a) and NRC (2007). Presently these methods seem most useful in early screening of wind resource areas for potential conflicts with birds and bats similar to the study of avian use in southwestern Minnesota described by Hawrot and Hanowski (1997), in evaluation of a site selected for potential development similar to the study of the Mount Storm site in West Virginia described by Mabee et al. (2006), and in research on the mechanisms of impact such as the study of bat interactions with a wind turbine described by Horn et al. (2008).

Mortality is the primary indicator of negative impact to individual animals from a wind facility. Mortality can be calculated from an estimate of fatalities. To use carcasses in assessing a wind facility as a cause of fatalities, all carcasses located within areas surveyed (regardless of species), should be recorded and a cause of death determined, if possible (the USFWS may assign a cause of death for legal purposes). Not all carcasses will be whole animals. The condition of each carcass found should be recorded using condition categories such as:

- *Intact* - carcass that is completely intact, is not badly decomposed, and shows no sign of being fed upon by a predator or scavenger.
- *Scavenged* - entire carcass that shows signs of being fed upon by a predator or scavenger or a portion(s) of a carcass in one location (e.g., wings, skeletal remains, legs, pieces of skin, etc.).
- *Feather spot or feather tract* - 10 or more feathers at one location indicating predation or scavenging.

The estimated time of death, season of death, and species can be important in interpreting fatalities. There is always the possibility that death was not caused by striking the turbine, so care should be taken in assigning a cause of death (e.g., shooting, poisoning). In certain situations a blind necropsy may be indicated.

In addition to carcasses, observers may discover live birds or bats that cannot fly, or have other physical abnormalities due to collisions with turbines or other injuries. These animals should be captured and examined to determine the cause of injuries. For injured birds or bats that cannot be captured, the species, location, and physical abnormalities observed should be described in the data. Injured animals should be treated in accordance with the appropriate laws and regulations.

Impacts of wind facilities on reproduction can be measured. In Level I studies the most common measure of reproductive performance will be through nest surveys. For example, the number and distribution of active nests within an area potentially impacted by the placement of wind turbines over time represents an index to the status of the breeding population of raptors. The area influenced by wind turbines will extend varying distances depending on the size of the area utilized by individuals of the species of interest. Passerines may range only a few hundred meters while raptors can range 20 or more kilometers. For species with multiple nest structures, the number of breeding pairs is of more value than occupied nests when evaluating breeding population status. Other factors that are changing within and around the wind development, such as roads, housing, and recreational activities, might also impact wildlife and should also be considered in any analysis.

Nesting surveys for smaller species such as passerines, some shore birds, and ground nesting birds are best accomplished on foot using ground surveys (Ralph et al. 1993). Unless the area is completely covered, previously described sampling protocols should be followed. For larger species, such as raptors, study areas should be surveyed initially when possible by air, preferably by helicopter, during the height of the nesting period. Aerial surveys should be followed immediately by ground surveys to confirm the species and status of each observed nest. Ground visits to occupied nests should be continued, to confirm the number of young fledged. Surveys should begin early enough to detect early nesters, such as eagles, and continue until all species of interest have begun nesting activity.

Empirical data on nesting pairs should be collected for all species of interest. In addition, the numerous reproductive parameters should be estimated to augment empirical data. The number of occupied nests within the defined area can be used to estimate relative abundance of nesting species potentially affected by the wind turbines. The following nest and territory parameters are suggested:

- *Occupancy rate* - the number of occupied territories (nests) per number of territories (nests) checked.
- *Breeding pair density* - the number of breeding pairs per area surveyed.
- *Reproductive rate* - the number of reproductive pairs per number of occupied territories.
- *Fledging success rate* - the number of pairs fledging young per number of reproductive pairs.
- *Breeding rate* - the number of young fledged per number of reproductive pairs.

Statistical comparisons of these parameters, if sufficient data exist, can be made among assessment and reference areas before and after construction.

Data on the above parameters will contain numerous biases, most of these related to the sampling method, data collection methods used (e.g., radar, visual, etc.), and observer and detection biases. Biases associated with sampling methods have been discussed previously. Biases associated with data collection methods may be found in numerous reference publications including Bibby et al. (1993), Buckland et al. (1993), Bookhout (1994), Edwards et al. (1981), Gauthreaux (1996), and Reynolds et al. (1980).

*Selection of Impact Indicators*
Impact indicators should allow for the determination of impact following generally accepted scientific principles. Stakeholders should believe that the criteria for determination of impact will be satisfied by the indicators at the end of the assessment period.

Of course, other indicators that are believed to provide useful information for analysis or for corroboration of results also should be measured. In the end, studies should be designed to:

- Quantify indicators that will allow convincing arguments that impacts did or did not occur.
- Quantify the magnitude and duration of the impact with acceptable measures of precision and accuracy.
- Allow for standardized comparisons among populations and with results of other studies.

In an ideal world, a study of birds or bats and wind facilities would involve a direct count of birds or bats using or passing through the wind facility, behaviors putting birds and bats at risk, and a count of fatalities caused by wind turbines and related facilities. To count birds, bats and behaviors one would need to identify individuals. To count fatalities one would need to detect carcasses before removal by scavengers and be 100 percent confident of the cause of death. This level of effort is not possible in most post-construction fatality studies.

As an alternative, studies of wind energy/animal interactions must rely on estimation of parameters that allow the test of hypotheses. These parameters are often expressed as rates, similar to epidemiological studies. Mayer (1996) provides an excellent discussion of the use of epidemiological measures to estimate the effects of wind facilities and related facilities on bird species. He points out the importance of selecting the appropriate denominator when developing a rate for use in comparisons of effect. For example, a comparison of the number of bird fatalities per turbine among portions of a wind facility, between two turbine types, or among several wind facilities, is much more meaningful if an estimate of bird abundance is added to the denominator.

There are a limited number of parameters that one can measure in an observational study. The more likely parameter candidates and some potential risk indices are listed here and described below.

- Bird utilization counts
- Bird utilization rate
- Dead bird counts (fatality)
- Bird mortality (fatality rate)
- Removal rate
- Observer bias
- Detection bias

There is little doubt that the presence of a wind facility will increase the risk of individual bird fatalities. This may be of great concern if the individual birds at risk have some special significance, as in the case of an extremely rare species. Risk of individual fatalities may be of interest when planning the design or location of a new wind facility, evaluating differences among turbine types, or when making modifications in equipment. *However, the risk of individual fatalities may not necessarily represent a risk to a population of birds.* Studies of risk to individuals and populations require separate study designs. Normally, observational studies will be designed to make direct statistical and deductive inference to risk to individuals and indirectly indicate risk to populations. More advanced studies normally will be needed to estimate risk to populations.

*Metrics Definitions*

***Bird utilization counts.*** Utilization counts are indices of relative abundance among plots, areas, and seasons. Utilization counts represent observations of individual birds from an observation point or transect conducted repeatedly over some time period to document behavior and relative abundance of birds using the area. The observer counts the length of time the bird is within the plot and estimates “bird minutes” of use. The bird utilization counts allow comparisons among defined time periods (e.g., seasons, migration periods, or years), and areas. Bird activities should include behaviors which could be related to risk of injury or mortality from wind facilities and might include flying, perching, soaring, hunting, foraging, height above ground, and behavior within 50 meters of WRA structures, etc. In situations of high bird density where it is impossible to keep track of all birds in a plot, use can be estimated for the observation period by making instantaneous counts repeatedly during the counting time period.

***Bird utilization rate.*** This term refers to the number of birds observed or the number of bird minutes recorded per count period and/or survey plot. Like bird utilization counts, bird utilization rate may be used for comparisons among plots, areas, and seasons. One formula for utilization rate is:

$$\frac{\text{\# birds observed}}{\text{time or time and area}} = \text{Bird Utilization Rate}$$

Utilization rates within specified distances of wind facility structures (e.g. large and small turbines, different tower types, etc.), subdivided on the basis of relevant environmental covariates (e.g. topographic features, vegetation edge, nesting structures, etc.) can be derived from the bird utilization counts. Rates can be developed for species, taxonomic groups, all birds observed, natural communities, seasons, distance from nearest turbine, turbine type, and other variables. Rates can be calculated for specific behaviors and risk can be evaluated in terms of the number of birds observed exhibiting behaviors that place them at greater risk. For example, birds flying at heights within the range of the rotor swept area are likely at greater risk than those consistently flying at heights above and below the rotor swept area. Evaluation of risk based on behavioral data can be used in a variety of studies of wind energy including relative comparisons of areas, turbines, and species. The choice of a utilization rate is critical; see discussion below.

***Dead bird count.*** Searches are conducted in a defined area with complete coverage to detect bird fatalities. The number of dead birds found (fatalities) at each search site (e.g., a 50-meter diameter circle centered on the bird utilization count site) is documented. Information is collected which will aid in analysis later in the study. This may include bird species, sex, age, estimated time since death, cause of death, type of injury, distance and direction to nearest turbine, and distance and direction to nearest structure.

***Bird mortality.*** The number of dead birds documented per search site may be termed “bird mortality.” This is the rate of fatalities. Examples of indices for bird mortality are:

$$\frac{\text{\# dead birds}}{\text{turbine}}, \quad \frac{\text{\# dead birds}}{\text{name plate MW}}, \text{ and } \frac{\text{\# dead birds}}{\text{unit rotor swept area}}$$

***Removal rate.*** This is the rate at which bird carcasses are removed by scavengers or by other means (e.g., human removal), resulting in their loss to detection by the dead bird search. Information about removal rates is necessary when estimating the total number of dead birds in a given area. The results are used to adjust the number of dead birds detected. This rate may be determined by placing a known number of bird carcasses at randomly chosen locations and monitoring them for removal. Removal rates can be calculated as a rate or rate/area. This allows for comparison of removal levels between different locations or subareas within the WRA. If not detected, significant removal rate differences would result in misleading bird risk rates. If removal rates in different areas within the same WRA or between WRAs are equal, they will have no effect when computing and comparing mortality rates, bird risk rates, and attributable risk rates.

***Observer bias.*** Observer bias is a quantification of the observer's ability to find dead birds or detect live birds. One study might quantify the observer's ability to find dead birds when a known number of birds are placed in the search area. Another study might compare the field crew's live bird observations in order to determine inter-observer differences.

***Detection bias.*** Detection bias is a measure of the differences in detection probability due to topography and vegetative structure. Detection bias may be determined through a designed study which includes placing a known number of dead birds in a variety of locations with differing topography and vegetative structure. The detection success can be quantified and the probability of detection determined.

*Defining Utilization*

If risk is defined as the ratio of dead or injured birds to some measure of utilization, then the choice of the use factor, or denominator, is more important than the numerator (number of dead or injured birds). In fact, the treatment effect is usually small relative to the variability that would arise from allowing alternative measures of risk. The choice arises from the preliminary understanding of the process of injury or death. For example, should the denominator be bird abundance, bird flight time in the facility, bird passes through the rotor plane, or some other measure of use? Unless these measures are highly correlated with death – which may be unlikely – then the measure selected will result in quite different measures of mortality. Further, the choice of denominator should express the mechanism causing the injury or mortality. If it does not, then it cannot be used to measure accurately the effectiveness of a risk reduction treatment. There is, however, much uncertainty in the mechanism(s) leading to bird fatalities in wind facilities.

***Choice of utilization factor.*** Suppose that bird use or abundance is selected as the denominator, with bird deaths as the numerator, and painted blades as the treatment. A treatment-reference study determines that death decreases from 10 to 7 following the treatment, but use also decreases from 100 to 70 (arbitrary units). It thus appears that the treatment had no effect because both ratios are 0.1 (10/100 and 7/70). There are numerous reasons why bird use of a wind facility could change (up or down) that are independent of the blade treatment; for example, changes in prey availability, deaths on wintering grounds, environmental contaminants, change of land use, and so on. Thus, unless it can be established that there is a direct link between the number of birds using the area and flights near a turbine, this study may be seriously flawed. Recording bird flights through the rotor plane of painted blades would have yielded a more correct measure of effect. In addition, the use of selected covariates can help focus the analysis on the treatment effects. Naturally, the hypothetical study noted above should be adequately replicated if implemented.

***Surrogate utilization variables.*** Utilization is an indicator of the level of at-risk behavior. Thus, adopting a measure of utilization requires the assumption that the higher the utilization, the higher the fatalities. It is, of course, prohibitive from a practical standpoint to record every passage of a bird through a zone of risk (be it a rotor plane or the overall wind facility). Further, it is usually prohibitive to census the population accurately and tally all deaths. Researchers must usually rely on surrogate variables to use as indices of population size and death. A *surrogate variable* is one that replaces the outcome variable without significant loss in the validity or power of the study. For example, researchers might use the number of birds observed during 10-minute point counts (i.e., the number of birds counted during a 10-minute observation period) as a measure of utilization (for either a treatment or reference case).

Once a measure of mortality is chosen, a measure of effect must be selected. This measure could be the *risk ratio*, defined as the ratio of mortality in one area (e.g., wind facility) to that in another area (e.g., reference). Thus, if mortality in the wind facility is 0.01 and that in the reference area is 0.001, the risk ratio is 10; the relative (potential) risk of death is 10 times greater for a randomly chosen bird in the site versus one in the reference area. Ideally, such a study should be adequately replicated, because references are not perfect matches to their associated treated sites. An alternative is to use one of the measures of attributable risk, described above. These measures have the advantage of combining relative risk with the likelihood that a given individual is exposed to the external factor. This results in the proportional change in the risk of injury or death attributable to the external factor. Whereas the risk ratio ignores the absolute size of the risk, the use of attributable risk implies that the importance of the risk is going to be weighed by the absolute size of the risk.

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