The Wildlife Society

Impacts of Wind Energy Facilities on Wildlife and Wildlife Habitat

Technical Review 07–2
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COVER: Wind turbines at the Maple Ridge Wind Farm in Lowville, New York (center): Ed Arnett, Bat Conservation International; Silver-haired bat (left): Merlin D. Tuttle, Bat Conservation International; Bluetit in spring (upper right); Greater prairie chicken (lower right): U.S. Geological Survey.

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Foreword

Presidents of The Wildlife Society occasionally appoint ad hoc committees to study and report on select conservation issues. The reports ordinarily appear as either a Technical Review or a Position Statement. Review papers present technical information, and position statements are based on these reviews. Preliminary versions of position statements are published for review and comment by Society members. Following the comment period, revision, and Council's approval, the statements are published as official positions of The Wildlife Society.

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Table of Contents

SYNOPSIS

Development of wind power offers promise of contributing to renewable energy portfolios to reduce greenhouse gas emissions from carbon-based sources, which contribute to accelerating climate change. This report summarizes information on the impacts of wind energy facilities on wildlife and wildlife habitat, including state and federal permitting processes, wildlife fatality, habitat loss and modification, animal displacement and fragmentation, offshore development, and issues surrounding monitoring and research methodology, including the use of technological tools.

Impacts of wind energy facilities on wildlife can be direct (e.g., fatality, reduced reproduction) or indirect (e.g., habitat loss, behavioral displacement). Although fatalities of many bird species have been documented at wind facilities, raptors have received the most attention. Turbine characteristics, turbine siting, and bird abundance appear to be important factors determining risk of raptor fatalities at wind energy facilities. In comparison with other sources of fatality (e.g., collision with buildings and communication towers, predation by domestic cats), wind turbines, at the current rate of development, appear to be a relatively minor source of passerine fatalities, but these fatalities are cumulative with other sources and their impact may become more pronounced over time. As turbine size increases and development expands into new areas with higher densities of birds, risk to birds could increase. Bat fatalities have been recorded either anecdotally or quantified at every wind facility where post-construction surveys have been conducted, worldwide, and reported fatalities are highest at wind facilities located on ridges in eastern deciduous forests in the United States. However, recent reports of high numbers of bats killed in open prairie in southern Alberta, Canada, and in mixed agriculture and forest land in New York raise concern about impacts to bats in other landscapes. Because bats are long-lived and have exceptionally low reproductive rates, population growth is relatively slow and their ability to recover from population declines is limited, increasing the risk of local extinctions. Given the projected growth of wind power generation, it is essential that future analysis of the impacts of wind energy development consider population effects for some species of bats and birds.

Often overlooked are impacts resulting from loss of habitat for wildlife due to construction, the footprint of the facility, and increased human access. Future development of transmission lines to facilitate wind generation will exacerbate the impacts of wind energy development on wildlife. Ultimately, the greatest impact to wildlife from habitat modification may be due to disturbance and avoidance of habitats in proximity to turbines and fragmentation of habitat for wide-ranging species. For example, habitat for many species of grassland birds in the Northern Great Plains has been dramatically reduced by land use changes, primarily agriculture, and further development of wind energy in undisturbed native and restored grasslands may result in further declines of these species.

Offshore wind facilities have been established throughout Europe, but few studies have been conducted to determine direct impacts on animals. A major concern with offshore developments in Europe has been loss of habitat from avoidance of turbines and the impact that boat and helicopter traffic to and from the wind development sites may cause with regard to animal behavior and movements, although little is known about such effects. Resident seabirds and rafting (resting) waterbirds appear to be less at risk than migrating birds, as they may adapt better to offshore wind facilities. The effects on marine mammals and bats are currently unknown. Although wind turbine/bird collision studies seem to indicate that onshore wind-generating facilities in those locations of the United States studied to date result in few fatalities compared with other sources of collision mortality, we cannot assume that similar impacts would occur among birds (or bats) using wind-generating sites established in unstudied areas such as coastal and offshore areas.

There is a dearth of information upon which to base decisions regarding siting of wind energy facilities, their impacts on wildlife, and possible mitigation strategies. With few exceptions, most work conducted to date at terrestrial facilities has been relatively short-term (e.g., one year or in some cases only one field season). Longer-term studies are required to elucidate patterns and develop predictive models for estimating fatalities and evaluating possible habitat fragmentation or other disturbance effects. The shortage of studies published in the scientific literature on wind-wildlife interactions is problematic and must be overcome to ensure the credibility of studies.

Potential mitigation measures exist and their effectiveness should be evaluated before mandated on a large scale. New mitigation measures are needed and effort must be focused on their development and evaluation. Mitigation measures can be patterned after other efforts that have been demonstrated to work. For example, conservation reserve program lands have replaced some habitat lost to grassland species as a result of agriculture.

Development of clean, renewable energy sources is an important goal, and wind power offers promise for contributing to renewable energy portfolios. However, given the projected development of wind energy, biologically significant cumulative impacts are possible for some species and may become more pronounced over time, unless solutions are found. Avoiding, minimizing, and mitigating harmful impacts to wildlife is an important element of "green energy" and developers of wind energy sources should cooperate with scientists and natural resource agency specialists in developing and testing methods to minimize harm to wildlife.

INTRODUCTION

Economically developed countries worldwide, most notably the United States, are highly dependent on fossil fuels to supply their energy needs. Conventional power generation from fossil fuels has a host of well-documented environmental impacts, globally the most notable being the emission of carbon dioxide (CO_2). The IPCC (2007) documents and projects significant and rapid world-wide changes in climate from increased atmospheric CO_2 concentrations, including rising temperatures, altered precipitation patterns, more severe extremes in droughts and floods, and rising sea levels. These changes in climate are already having significant impacts on flora and fauna (Parmesan 2006), which must adapt to changing environmental conditions (Inkley et al. 2004) if they are to survive.

Increasingly, the world is looking for alternatives for supplying energy. Alternatives frequently considered are nuclear, coal with CO_2 sequestration (i.e., capture and storage of CO_2 and other greenhouse gases that otherwise would be emitted into the atmosphere), conservation, and renewable energy. Conservation and energy-efficiency are perhaps the most cost-effective options, but they alone cannot fill the gap between growing demand for energy and available supply, while simultaneously reducing carbon emissions.

Wind has been used to commercially produce energy in North America since the early 1970s and currently is one of the fastest-growing forms of renewable energy worldwide (Figure 1), at a time of growing concern about the rising costs and long-term environmental impacts from the use of fossil fuels and nuclear power (McLeish 2002, Kunz et al. 2007a). Of the renewable energy technologies, wind-generated electricity is becoming cost-effective in many locations, and electrical utilities in the United States and Europe are increasingly turning to wind energy for new electricity supplies that are free of emissions and carbon. Wind turbines are able to generate electricity without many of the negative environmental impacts associated with other energy sources (e.g., air and water pollution, greenhouse gas emissions associated with global warming and climate change). The National Energy Modeling System (NEMS) model projects that the installed capacity of wind generators will grow to about 100,000 megawatts (MW) over the next 20 years and that these generators will displace approximately the equivalent of 69 million metric tons of carbon, while avoiding the installation of 17,000 MW of conventional generating capacity and saving energy consumers about $17.6 billion/year on energy costs.

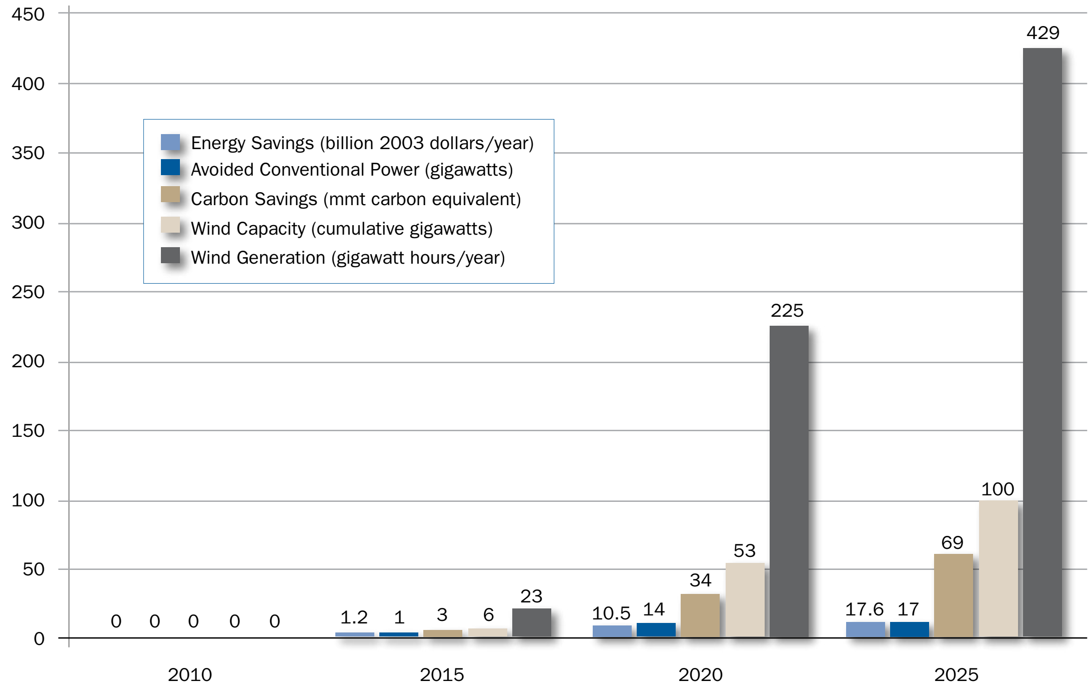
Some wind experts project that wind energy could ultimately contribute 20 percent of the United States' electrical energy needs, as Denmark has already achieved (Advanced Energy Initiative 2006). This would amount to about three times the installed capacity projected by the NEMS model, and while the various quantities in the figure do not scale linearly, the benefits would be roughly three times greater. Wind energy detractors, however, argue that while wind energy is growing exponentially in the United

States, fossil-fuel-burning power plants also continue to grow exponentially. Thus, while wind is producing more electricity, based on public demand, it is not replacing fossil fuels. Indeed, the proportion of fossil-fuels in the world's energy mix, currently at 86 percent, is not projected to change by 2030 (EIA 2007). Whether wind energy ever provides 20 percent of electricity in the United States will depend on many variables, not the least of which is connectivity to the power grid.

However, wind energy development is not environmentally neutral. Often overlooked are habitat impacts, both direct (e.g., resulting from turbine construction and increased human access) and indirect (e.g., habitat fragmentation and avoidance of habitats in proximity to turbines). Better known are fatalities of birds and bats that have been documented at wind facilities worldwide, including Australia (Hall and Richards 1972), the United States and Canada (e.g., Erickson et al. 2002, Johnson et al. 2002, 2003ab), and northern Europe (e.g., Ahlen 2003, Dürr and Bach 2004, Brinkman 2006). Raptor fatalities have been well documented in California (e.g., Orloff and Flannery 1992, Smallwood and Thelander 2004). Furthermore, recent reports of large numbers of bats being killed at wind energy facilities (e.g., Fiedler 2004, Kerns and Kerlinger 2004, Arnett 2005, Arnett et al. 2008) raise concerns about potential cumulative population-level impacts. Wildlife research related to wind energy has focused primarily on bird collisions with wind turbine blades, towers, support structures, and associated power lines (Erickson et al. 2001, Orloff and Flannery 1992). Wildlife advocates and experts have been slower to grasp other potential impacts of wind power development, such as bat fatalities and habitat effects.

This report summarizes information on the impacts of wind energy facilities on wildlife and wildlife

Figure 1. Projected growth and usage of wind energy in the U.S. through 2025, (National Renewable Energy Laboratory 2006).



habitat primarily at land-based facilities. We present information on world energy demands, wind energy development and technology, state and federal permitting processes, wildlife fatality, habitat loss (including modification, animal displacement, and fragmentation), offshore development, and issues surrounding monitoring and research methodology and use of technological tools. We also discuss information needs for siting wind energy facilities and the need to monitor wind energy impacts so that agency managers and biologists, researchers, decision makers, wind industry, and other stakeholders are sufficiently informed about impacts to help avoid, minimize, and mitigate impacts of wind energy facilities on wildlife and wildlife habitat.

FEDERAL AND STATE REGULATIONS AND PERMITTING

Federal resource and land management agencies, non-governmental organizations, contractors, developers, and utilities have dominated the discussion about wildlife interactions with wind energy facilities. Until recently, most state fish and wildlife agencies have not been deeply or proactively involved. This limited participation reflects a variety of factors, including more immediate management priorities, lack of fiscal and human resources, and the limited regulatory authority to apply wildlife considerations to these decisions. These facts notwithstanding, wind energy regulation in most of the United States is primarily the responsibility of state and local governments. First, most North American wind energy development has occurred and is occurring on private land (Government Accountability Office [GAO] 2005). Second, with the exception of federal trust species (Sullivan 2005), wildlife conservation in the United States lies within the exclusive jurisdictional authority of state fish and wildlife agencies (Baldwin vs. Fish and Game Commission of Montana 1978, Manville 2005). Federal jurisdiction over wildlife habitat is limited to sites located on federally owned lands, or where federal funding or federal permits are involved, or Critical Habitat designated under the federal Endangered Species Act. Several states have set up wind working groups to address issues and advise legislators and regulators about the potential impacts and benefits of wind development, including effects on wildlife resources.

Where wind projects are proposed for development in federal waters (generally > 3 NM [5.6 km], or for Texas, 3 leagues [~10.2 mi; 16.3 km]), the Interior Department's Minerals Management Service (MMS) now has jurisdictional authority. At this writing, MMS is developing an EIS review process under the National Environmental Policy Act. In Texas State waters, the Texas Lands Office retains siting authority. In the Great Lakes, the Army Corps of Engineers retains authority for offshore wind development.

Federal Regulatory Approaches

The primary federal laws that pertain to wind energy development, permitting, and impacts on wildlife include the MBTA (16 U.S.C. 703-712; MBTA), Bald and Golden Eagle Protection Act (16 U.S.C. 668-668d; BGEPA), Endangered Species Act (16 U.S.C. 1531-1544; ESA), and the National Environmental Policy Act (16 U.S.C. 4371 et seq.; NEPA). Strict liability statutes under the MBTA and BGEPA, which lack a consultation process, require developers of wind energy on private and federally owned lands to perform within the spirit and the intent of these laws. Under the ESA, development of a Habitat Conservation Plan (Section 10) and subsequent acquisition of a "takings permit" are voluntary on the part of the developer, but any violation of the ESA is not. Other relevant aspects of facility development require compliance with federal laws and regulations such as the 404 b(1) of the Clean Water Act and use of aircraft warning lights, as required by the Federal Aviation Administration (FAA) under its current "obstruction marking and lighting" Advisory Circulars.

There currently is no oversight agency or commission tasked to review and regulate wind energy development on private lands, which complicates regulation among local, state, and federal governing bodies. How the federal government and specific federal agencies tasked to address issues related to wind development deal with wind siting, permitting, and development depends on a federal "nexus" or specific federal connection related to the proposed site. A federal nexus would include wind development 1) on federal lands or waters; 2) where federal funding has been provided to a project; 3) where a federal permit is involved; or 4) where there is a connection to a federal power grid, such as the Bonneville Power Authority (BPA) or the Western Area Power Administration (WAPA) transmission grids. While the federal production tax credit (currently $0.019/kilowatt [Kw] hour) is a tax-payer-financed subsidy, currently authorized through the end of 2008, it is not currently considered a federal nexus, has not yet been challenged in court, and thus does not require NEPA review. Where a commercial wind facility intends to connect to a federal power grid such as BPA or WAPA, the U.S. Department of Energy requires environmental review under NEPA. For wind development on private lands, where no federal permit or no federal funding is involved, no clear federal nexus presently exists. While NEPA typically evaluates proposed projects in terms of biological significance, ESA protects both individuals and populations, and strict liability statutes, such as the Migratory Bird Treaty Act, make it difficult for federal agencies to address only population impacts (Manville 2001, 2005).

To assist U.S. Fish and Wildlife Service (USFWS) staff, particularly those in the Service's 78 Ecological Services Field Offices whose task is to provide technical assistance to wind developers or their consultants, the Service developed interim voluntary land-based guidance to avoid or minimize impacts to wildlife and their habitats (found at www.fws.gov/habitatconservation/wind.pdf, May 13, 2003, Deputy Director's cover memo, and pp. 1–33, 52–55, released to the public on July 10, 2003). The voluntary guidance was intended to allow Field Offices to help wind developers avoid future take of migratory birds and federally listed threatened and endangered species, as well as minimally impact their habitats. The guidelines do this by making recommendations on the proper evaluation of potential sites; the proper location and design of wind turbines, and their associated infrastructures; and by suggesting pre- and post-construction research and monitoring to identify and assess risk and potential impacts to wildlife. While voluntary, the guidelines will remain in use until they are updated with recommendations from an advisory committee soon to convene.

State Regulatory Approaches

As of 2006, 11,603 MW of wind energy capacity was installed in the United States (Figure 2; U.S. Department of Energy 2006). Development is concentrated where adequate wind resources and transmission currently exist. At present, 16 states are without any wind power facilities (Alabama, Arizona, Arkansas, Connecticut, Delaware, Florida, Georgia, Indiana, Kentucky, Louisiana, Maryland, Mississippi, Nevada, North Carolina, South Carolina, and Virginia), although some have projects proposed or under development.

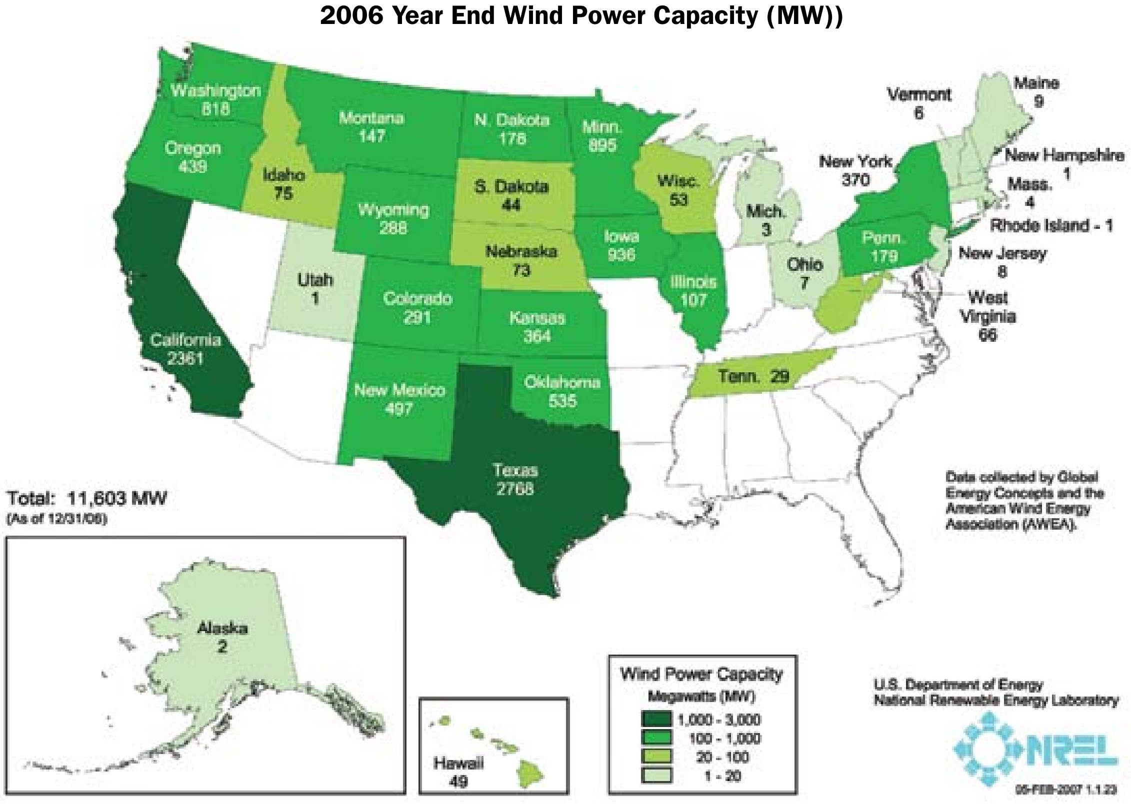
State fish and wildlife agency participation in wind energy development has varied from proactive involvement with clear regulatory guidance (e.g., Washington) to piecemeal reactive involvement with specific projects of special concern. With several notable exceptions, most states have statutes that can be applied (albeit indirectly) to regulate the siting, construction, and operation of wind energy facilities. These include industrial siting laws, zoning regulations, state environmental laws, and home-rule requirements at the local level (e.g., New York), among others. To date, state and local governments have used these authorities to encourage development rather than as a basis for litigation. Typically, state public service commissions, local or county planning commissions, zoning boards, and/or city councils are the permitting authorities for wind development projects (GAO 2005). Given this diversity, it is not surprising that there are considerable differences in the requirements imposed. Currently, several states (e.g., Vermont, Pennsylvania, and California) are in the process of developing state guidelines and regulations to address wind energy development (Stemler 2007).

More often than not, state fish and wildlife agencies lack regulatory authority to directly participate in the permitting of any type of development, and so instead rely on cooperating with the state regulating authority and federal partners, such as the Bureau of Land Management (BLM), to control when and where development occurs. This approach is only moderately effective because wildlife concerns are only one of a myriad of social, political, and economic inputs considered by decision-makers. State natural resource or environmental agencies, historic preservation boards, industrial development boards, public utility commissions, or siting boards often provide an additional level of oversight (in many cases, state authorities supersede local oversight). This involvement also varies among jurisdictions, reflecting the evolution of authorities in response to the growth of the industry. Pre-existing authorities to regulate development often are insufficient, ill-suited, or simply not applicable to wind energy projects. Compounding this difficulty, state and local governments sometimes lack the experience, staff, and capability necessary to adequately address the environmental impacts of wind energy development.

A critical point is that while many species potentially affected by wind energy development are under federal jurisdiction, others, such as prairie and sage grouse, mule deer, and bighorn sheep, are not, unless they become federally listed under the ESA. These species are managed by state fish and wildlife agencies, and, at least in the states that comprise major portions of their core habitat, the lack of regulatory authority compromises conservation and restoration objectives. Enhancing legislative authorities for state fish and wildlife agencies related to all forms of development, including wind energy, is the purview of the states involved.

A growing number of states have (or are developing) Renewable (Energy) Portfolio Standards (RPS) (Stemler 2007). In most cases, these are numerical targets requiring utilities to increase reliance on solar radiation, wind, water, and other renewable sources for electrical generation (American Wind Energy Association 1997). The Western Governors Association Clean and Diversified Energy Initiative for the West (WGA Proposed Policy Resolution 04-12, 2004) proposes to encourage development of RPS across the western United States. In 2001, 75 percent of wind power developed in the United States was in states with portfolio requirements. Some believe that RPS or purchase mandates are the most powerful tool that states can implement to promote renewable energy use (Bird et al. 2003). Unfortunately, RPS usually focus on benefits of renewable energy, with less attention to negative environmental impacts.

Figure 2. Installed wind capacity (megawatts; MW) in the United States as of 31 December 2006 (National Renewable Energy Laboratory; http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_installed_capacity.asp)



Washington Department of Fish and Wildlife Wind Power Guidelines

Among state fish and wildlife agencies, the Washington Department of Fish and Wildlife was the first to provide comprehensive guidelines for wind energy development (Washington Department of Fish and Wildlife 2003). These guidelines consist of three sections: (a) baseline and monitoring studies for wind projects, (b) wind project habitat mitigation, and (c) wind power alternative mitigation pilot program. The guidance applies to projects east of the Cascade Mountains in sage steppe habitats.

Baseline and monitoring studies for wind projects. Developers, in consultation with the agency, are required to collect information about potential environmental impacts. Site-specific components of the assessment include project size, availability of existing comparison baseline data, habitats affected, and the likelihood and timing of threatened, endangered species, and state-sensitive species occurring in the proposed project location. The guidance requires use of the best available evaluation protocols and communication of baseline and pre-construction study results to stakeholders (i.e., state agencies and other groups with an interest in the siting, construction, and operation of facilities).

Developers are required to conduct habitat mapping and report general vegetation and land cover types, habitats for wildlife species of concern, and the extent of noxious weeds at the development location. At least one raptor survey during the breeding season is required. If the occurrence of threatened, endangered, or state-sensitive species is likely, then monitoring within a 3.2 km buffer of the development location is recommended. At least one full season of general bird surveys is recommended during seasons of occurrence or for longer periods of time if avian use is high or if few data exist to indicate which seasons might be important. The guidelines also require state-of-the-art protocols that are reviewed and approved by the state wildlife agency.

The guidance recommends that developers use already disturbed lands (i.e., agricultural land, existing transmission corridors, established road systems), and it discourages the use of sites supporting high-value plant communities. It requires the use of tubular towers and discourages the use of guy wires either on turbine or associated meteorological towers. The guidance makes a series of recommendations with the intent of reducing impacts, including minimizing overhead power lines, minimizing lighting on turbines (to the extent permitted under Federal Aviation Administration [FAA] regulation), encouraging noxious weed control, and requiring a fire protection plan. The guidance requires that development locations be restored to (at least) pre-development conditions when turbines are decommissioned.

When a wind energy facility becomes operational, the guidance requires ongoing monitoring, the scope of which depends on size of the project and availability of data from similar projects. A Technical Advisory Committee reviews and evaluates mitigation actions (included as conditions of the permitting document) on a quarterly basis. Research studies are encouraged, but not as part of an operational monitoring plan.

Wind project habitat mitigation. The Washington guidance indicates that mitigations specified in permitting documents are considered to be entirely adequate, except for any subsequently identified impacts to threatened, endangered, and state-sensitive species. Developers are required to acquire and then manage replacement wildlife habitat for the life of the project, unless the development occurs on land with little or no wildlife habitat value (land under cultivation or otherwise developed or disturbed). The acquisition of replacement habitat is guided by five criteria: (1) replacement lands should be comparable to habitat disturbed by development; (2) replacement habitat should be given legal protection; (3) replacement habitat should be protected from degradation for the life of the project; (4) replacement habitat should be in the same geographic region as the project; (5) replacement habitat should be jointly agreed to by the developer and the Washington Department of Fish and Wildlife.

The area of replacement habitat varies depending on the value of the disturbed land. The ratio is 1:1 for habitat subject to imminent development, or to acquisition for grassland or CRP replacement. The ratio is 2:1 for sage steppe plant community replacement. When disturbance is temporary, the replacement ratios are 0.1:1 for habitats subject to imminent development and 0.5:1 for sage steppe plant community. Replacement habitats must be prepared and seeded, noxious weeds must be controlled, and the land otherwise protected from degradation.

Alternative mitigation pilot program. Developers can pay a median fee of $55.00/acre to the Washington Department of Fish and Wildlife. This cost is reviewed annually and may be adjusted by up to 25 percent to reflect current land values and/or the quality of the disturbed habitat. Funding obtained is used to purchase and manage high-value wildlife habitat in the same geographic region as the development project.

No RPS consider the potential impacts of renewable energies development on fish, wildlife, and their habitats. Revising existing standards to account for wildlife impacts and inclusion of guidelines in the permitting process would further strengthen agency participation and implementation of guidelines.

WILDLIFE COLLISION FATALITY AT WIND FACILITIES

Factors Influencing Estimation of Fatality Rates

Experimental designs and methods for conducting post-construction fatality searches are well established (e.g., Anderson et al. 1999, Morrison 1998, 2002). While the statistical properties for at least some common estimators have been evaluated and suggested to be unbiased under the assumptions of the simulations (Barnard 2000, W. P. Erickson, Western Ecosystems Technology, unpublished data), important sources of field sampling bias must be accounted for to correct estimates of fatality. Important sources of potential bias include 1) fatalities that occur sporadically; 2) carcass removal by scavengers; 3) searcher efficiency; 4) failure to account for the influence of site (e.g., vegetation) conditions (Wobeser and Wobeser 1992, Philibert et al. 1993, Anderson et al. 1999, Morrison 2002); and 5) fatalities or injured animals that may land or move outside the search plots.

Fatality searches usually are conducted on a systematic schedule of days (e.g., every 3, 7, or 14 days). Most estimators assume fatalities occur at uniformly distributed, independent random times between search days and apply an average daily rate of carcass removal expected during the study. However, if the distribution of fatalities is highly clustered, then estimates may be biased, especially if carcass removal rates are high. If most fatalities occur immediately after a search, those fatalities 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 fatality estimate may be an overestimate. The second source of bias in fatality estimation relates to assessing scavenging rates (also referred to as carcass removal). Most studies have used house sparrows as surrogates for small birds and bats during carcass removal trials, while using pigeons for medium-sized birds (Erickson et al. 2001, Morrison 2002). While the use of these surrogates may be reasonable for birds, past experiments assessing carcass removal may not be representative of scavenging on bats in the field when small birds are used as surrogates for bats (Kerns et al. 2005). Scavenging of both birds and bats should be expected to vary from site to site and among both macro-scale habitats (e.g., forests compared with grass pasture) and micro-scale vegetation conditions at any given turbine (e.g., bare ground compared with short grass). As scavengers learn of the presence of available carcasses, scavenging rates may significantly increase. A third source of bias relates to detectability: the rate by which searchers detect bird and bat carcasses. Searcher efficiency can be biased by many factors, including habitat, observer, condition of carcasses (e.g., decomposed remains compared with 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). Proportion of fatalities that land outside of search plots can be estimated by using the distribution of fatalities as a function of distance from turbines (Kerns et al. 2005). Bias associated with injured animals that leave search plots is difficult to quantify and has not been reported to date.

Below, we discuss patterns and estimates of fatalities reported for raptors, resident and migratory

Estimates of bird and bat fatality at wind facilities are conditioned on field sampling biases such as searcher efficiency which varies considerably with vegetative conditions. (Credit: Merlin D. Tuttle, Bat Conservation International) songbirds, other avian species, and bats, but caution that estimates are 1) conditioned upon the above described factors, 2) calculated differently for most studies reviewed and synthesized here, and 3) may be biased in relation to how the sources of field sampling bias were or were not accounted for.

Raptors

Early utility scale wind energy facilities, most of which were developed in California in the early 1980s, were planned, permitted, constructed, and operated with little consideration for potential impacts to birds (Anderson et al. 1999). Although fatalities of many bird species have been documented at wind facilities, raptors have received the most attention (e.g., Anderson et al. 1996a, 1996b, 1997, 2000; Anderson and Estep 1988, Estep 1989, Howell 1997, Howell and Noone 1992, Hunt 2002, Johnson et al. 2000a, 2000b, Martí 1994, Orloff and Flannery 1992, 1996, Thelander and Rugge 2000, Smallwood and Thelander 2004). In the United States, all raptors are protected under the MBTA and several species are protected by the ESA. Initial observations of dead raptors at the Altamont Pass Wind Resource Areas (APWRA) (Anderson and Estep 1988, Estep 1989, Orloff and Flannery 1992) triggered concern about possible impacts to birds from wind energy development from regulatory agencies, environmental groups, wildlife resource agencies, and wind and electric utility industries. Raptors occur in most areas with potential for wind energy development, but appear to differ in their susceptibility to collisions. Early fatality studies only reported carcasses discovered during planned searches of wind facilities and did not account for potential survey biases described above. Contemporary fatality estimates are based on extrapolation of the number of observed fatalities at surveyed turbines to the entire wind power facility, corrected for searcher efficiency and carcass removal.

Older generation turbines. Earlier studies on fatalities at wind facilities occurred in California because most wind power was produced by three California facilities (APWRA, San Gorgonio, and Tehachapi). APWRA currently has 5,000 to 5,400 turbines of various types and sizes and with an installed capacity of approximately 550 MW (~102 kw/turbine), San Gorgonio consists of approximately 3,000 turbines of various types and sizes with an installed capacity of approximately 615 MW (~205 kw/turbine), and Tehachapi Pass has approximately 3,700 turbines with an installed capacity of approximately 600 MW (~162 kw/turbine). While some replacement of smaller turbines with modern, much larger turbines has occurred (i.e., repowering), all three of these facilities are populated primarily with relatively small “old generation” turbines ranging from 40 to 300 kw, with the most common turbine rated at approximately 100 kw. The best wind sites located within each facility have a relatively high density of turbines. Turbine support structures are both lattice and tubular, all with abundant perching locations on the tower and nacelle. Additionally, all three facilities have above-ground transmission lines. Perching sites for raptors are ubiquitous within all three facilities, but particularly at APWRA. Vegetation communities differ among the sites, with San Gorgonio being the most arid and Tehachapi the most montane.

Widely publicized reports of avian fatalities at Altamont prompted considerable scrutiny of the problem (Orloff and Flannery 1992). Subsequent industry attempts to reduce fatalities at APWRA have not significantly reduced the problem, as suggested by recent results of avian fatality studies conducted by Smallwood and Thelander (2004). Notwithstanding, the turbines studied by Smallwood and Thelander ranged from 40 to 330 kw, and small sample sizes for turbines greater than 150 kw make extrapolation of fatality rates to all turbines in the AWPRA problematic. Nevertheless, Smallwood and Thelander (2004) extrapolated their results to the entire wind resource area and estimated that 881–1,300[1] raptors are killed by collision at APWRA each year. These estimates translate to 1.5–2.2 raptor fatalities/MW/year. Fatality estimates include 75 to 116 golden eagles, 209 to 300 red-tailed hawks *(Buteo jamaicensis)*, 73 to 333 American kestrels *(Falco sparverius)*, and 99 to 380 burrowing owls *(Athene cunicularia)*. The number of burrowing owls was particularly disconcerting given that it is classified as a species of special concern in California. Hunt (2002) completed a four-year telemetry study of golden eagles at APWRA and concluded that while the population is self-sustaining, fatalities resulting from wind power production were of concern because the population apparently depends on immigration of eagles from other subpopulations

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[1] adjusted for scavenging and searcher efficiency from data at Oregon/Washington wind projects.

to fill vacant territories. A follow-up survey conducted in 2005, Hunt and Hunt (2006) reported on 58 territories in the APWRA and found that all territories occupied by eagle pairs in 2000 were also occupied in 2005. Early studies conducted at San Gorgonio documented relatively low raptor mortality (McCrary et al. 1983, 1984, 1986). More recent studies at San Gorgonio (Anderson et. al. 2005) and Tehachapi Pass (Anderson et al. 2004) also suggest lower raptor fatalities compared with APWRA. The unadjusted average per turbine and per MW raptor fatality rates, respectively, for these three sites are 0.006 and 0.03 for San Gorgonio, 0.04 and 0.20 for Tehachapi, and 0.1 and 1.23 for APWRA. Differences in fatality appear to be related to density of raptors on these facilities; APWRA has the highest density of raptors, presumably because of abundant prey (particularly small mammals), while San Gorgonio has the fewest raptors and Tehachapi Pass has intermediate densities of raptors (Anderson et al. 2004, 2005).

Newer generation wind facilities. Contemporary wind developments use a much different turbine than older facilities discussed above. In addition, many facilities have been constructed in areas with different land use than existing facilities in California. Results from 14 avian fatality studies, where surveys were conducted using a systematic survey process for a minimum of one year and scavenging and searcher efficiency biases were incorporated into estimates, indicate that combined mean fatality rate for these studies is 0.03 raptors per turbine and 0.04 raptors per MW (See Table 1 on page 47). Regional fatalities per MW were similar, ranging from 0.07 in the Pacific Northwest region to 0.02 in the East (Table 1). With the exception of two eastern facilities in forested habitats (68 MW; 7.5%), landuse/landcover is similar in all regions. Most of these facilities occur in agricultural areas (333 MW; 37%) including agriculture/grassland/Conservation Reserve Program (CRP) lands (438 MW; 48%), and the remainder occur in short grass prairie (68; 7.5%). Landscapes vary from mountains, plateaus, and ridges, to areas of low relief, but aside from size of rotor-swept area, all of these facilities had similar technology, including new generation turbines with lower rotational speeds (~15–27 rpm, but still with tip speeds exceeding 280 km/hr [175 mi/hr]), tubular towers, primarily underground transmission lines, FAA-recommended lighting, and few perching opportunities. Fatality search protocols varied, but all generally followed guidance in Anderson et al. (1999), although standard estimates of raptor use are not available for all 14 studies.

Two factors commonly associated with raptor collision risk are turbine type and bird abundance. Figure 3 illustrates the difference between raptor fatalities at older facilities in California and newer facilities in the United States outside of California. Fatality rates for older turbines are unadjusted for searcher detection and scavenger removal, while rates from the 14 sites with newer generation turbines are adjusted for these biases. Three of the four studies at older generation sites report higher fatality rates than at newer, larger turbine sites, even without bias adjustment. It is noteworthy that even though reported raptor fatalities are higher at older facilities, there is a rather dramatic difference among older facilities. Reported raptor fatalities at APWRA are higher than for Montezuma Hills (Howell 1997); fatalities are somewhat lower at Tehachapi (Anderson et al. 2004) and very few raptor fatalities are reported for San Gorgonio (Anderson et al. 2005). Because the three facilities have similar technology, this difference must be strongly influenced by other factors, most likely raptor abundance. The relationship of abundance and technology will be better addressed when it is possible to study old and new generation turbines in areas of varying raptor density. Three wind facilities in northern California, High Winds and Shiloh in Solano County and APWRA in Alameda County, may present such an opportunity when estimates of fatalities are published. Estimates of raptor use near the Solano County wind facilities are higher than the estimated use at APWRA. These estimates are based on numerous avian use studies conducted in both areas (e.g., Orloff and Flannery 1992, Smallwood and Thelander 2004). The Solano County sites have newer generation turbines and, with the exception of golden eagles, higher raptor use than APWRA.

Other factors such as site characteristics at wind facilities also may be important (Smallwood and Thelander 2004). Additionally, it is also possible that siting of individual turbines may relate to risk of collision and raptor fatalities. Orloff and Flannery (1992) concluded that raptor fatalities at APWRA were higher for turbine strings near canyons and at the end of row turbines. Smallwood and Thelander (2004) also concluded that fatalities were related to turbine site characteristics and position of turbines within a string. The implication of both studies is that turbine siting decisions during construction of a facility are important.

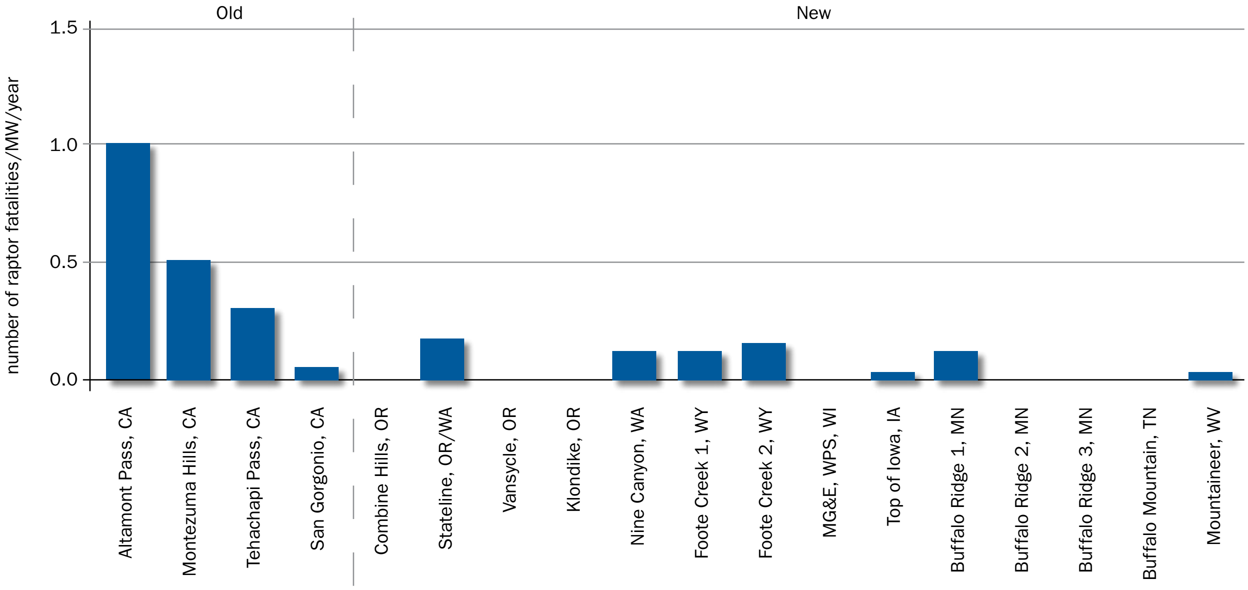
Resident and Migratory Passerines

The available data from wind facilities studied to date suggest that fatality of passerines from turbine blade strikes generally is not numerically significant at the population level (e.g., LGL Ltd. 1995, 1996, 2000; Nelson and Curry 1995; Osborn et al. 2000, Erickson et al. 2001, Strickland et al. 2001), but ill-sited facilities, particularly in areas where migrating birds are concentrated and in areas of abundance for rare species (e.g., listed songbirds, candidate species, and Birds of Conservation Concern), could constitute exceptions.

In a review of avian collisions reported in 31 studies at wind energy facilities, Erickson et al. (2001) reported that 78 percent of carcasses found at facilities outside of California were passerines that are protected under the MBTA. The balance of fatalities was waterfowl (5.3%), waterbirds (3.3%), shorebirds (0.7%), diurnal raptors (2.7%), owls (0.5%), gallinaceous (4.0%), other (2.7%), all protected under the MBTA, and non-protected birds (3.3%). Concerns have been raised by USFWS regarding fatalities at wind facilities of "Birds of Conservation Concern" (BCC) and birds whose populations have been declining based on Breeding Bird Survey (BBS) data. For example, 12 of 33 species reported retrieved were BCC and/or BBS declining from Buffalo Ridge, Minnesota (Johnson et al. 2002), seven of 19 species from northwestern Wisconsin (Howe et al. 2002), nine of 25 species from Mountaineer, West Virginia (Kerns and Kerlinger 2004), and eight of 24 species at Buffalo Mountain, Tennessee (Nicholson 2003).

Estimates of total passerine fatality vary considerably among studies conducted at 14 new generation facilities (see Table 1 on page 47), but fatalities per turbine and per MW are similar for all regions represented by these studies, although the two eastern sites studied suggest that more birds may be killed at wind facilities constructed on forested ridge tops in the East. The number of fatalities reported by in-

Figure 3. Fatality rates for raptors at four older generation turbines unadjusted for searcher efficiency and carcass removal bias (Smallwood and Thelander 2004, Howell 1997, Anderson et al. 2004, Anderson et al. 2005), and fatality rates adjusted for searcher efficiency and carcass removal at 14 wind projects (Erickson et al. 2000, 2003, 2004, Young et al. 2005, Johnson et al. 2003b, Young et al. 2003, Howe et al. 2002, Johnson et al. 2002, Jain 2005, Nicholson 2003, Kerns and Kerlinger 2004) with newer generation turbines.



dividual studies ranged from zero at the Searsburg, Vermont facility (Kerlinger 1997) to 11.7 birds/MW at Buffalo Mountain, Tennessee (Nicholson 2003). Most studies report that passerine fatalities occur throughout the facility, with no particular relationship to site characteristics.

Based on data from the 14 studies, it appears that approximately half the reported fatalities at new generation wind power facilities are nocturnally migrating birds, primarily passerines, and the other half are resident birds in the area. In reviewing the timing of fatalities at eight western and mid-western wind power facilities, it appears that fatalities of passerines occur in all months surveyed (e.g., Erickson et al. 2001, 2003a, 2004, Young et al. 2005, Johnson 2003a, Young et al. 2003, Howe et al. 2002, Johnson et al. 2002, Koford et al. 2004, Nicholson 2003, Kerns and Kerlinger 2004), although fatalities are most common from April through October. The timing of fatalities varies somewhat from site to site. For example, peak passerine fatalities occurred during spring migration at Buffalo Ridge, Minnesota (Johnson et al. 2002), and during fall migration at Stateline in Washington and Oregon (Erickson et al. 2004).

Vulnerability of birds colliding with wind turbines and associated infrastructures has not been thoroughly examined. Most fatalities at wind facilities are assumed to be from collisions with moving wind turbine blades, although there is no specific evidence suggesting that passerines do not occasionally collide with turbine support structures or stationary blades. Perhaps the most difficult task in interpreting breeding passerine fatalities is the estimation of exposure. The most common fatalities reported in western and mid-western wind power facilities are some of the more common species such as horned lark *(Eremophila alpestris)*, vesper sparrow *(Pooecetes gramineus)*, and bobolink *(Dolichonyx oryzivorus)*. These species perform aerial courtship displays that frequently take them high enough to enter the rotor-swept area of a turbine (Kerlinger and Dowdell 2003). In contrast, the western meadowlark *(Sturnella neglecta)*, also a common species, is frequently reported in fatality records, yet is not often seen flying at these altitudes. Also, corvids are a common group of birds observed flying near the rotor-swept area of turbines (e.g., Erickson et al. 2004, Smallwood and Thelander 2004), yet are seldom found during carcass surveys. Clearly, the role of abundance relative to exposure of birds to collisions with wind turbines is modified by behavior within and among species and likely varies across locations.

The estimation of exposure of nocturnal migrating passerines is even more problematic. Bird and bat "targets" identified by most radar systems currently cannot be distinguished, and not all targets are exposed to turbines because nocturnal migrating passerines are known to migrate at relatively high altitudes during favorable weather conditions, except during take-off and landing. Radar studies suggest there is a large amount of night-time variation in flight altitudes (e.g., Cooper et al. 1995), with targets averaging different altitudes among nights and at different times during each night. No doubt, some intra-night variation is due to birds landing and taking off at dawn and dusk, respectively. Kerlinger and Moore (1989) and Bruderer et al. (1995) concluded that atmospheric conditions affect choice of flight direction and flight height by migrating passerines. For example, Gauthreaux (1991) found that birds crossing the Gulf of Mexico appear to fly at altitudes at which favorable winds exist. Inclement weather has been identified as a contributing factor in avian collisions with other obstacles, including power lines, buildings, and communications towers (Estep 1989, Howe et al. 1995, Manville 2005). Johnson et al. (2002) estimated that as many as 51 of 55 collision fatalities discovered at the Buffalo Ridge wind facility may have occurred in association with inclement weather, such as thunderstorms, fog, and gusty winds. There is some concern that nocturnal migrating passerines may be compressed near the surface when cloud ceilings are low or when flying over high mountain ridges, increasing the risk of collisions with turbines. Estimating the effect of weather is problematic because marine radar is ineffective during rain events, but the association of avian fatalities at wind power facilities (e.g., Johnson et. al. 2002) and communications towers (Erickson et al. 2001, Manville 2005) with weather suggests this could be an issue. Recent radar evidence from studies in New York and Pennsylvania also shows that birds may vary their flight heights considerably, depending on weather conditions and landings/take-offs at stopover sites (ABR Inc. 2004).

The effect of topography on bird migration also is somewhat uncertain. It generally is assumed that nocturnal migrating passerines move in broad fronts and rarely respond to topography (Lowery and Newman 1966, Able 1970, Richardson 1972, Williams et al. 1977, Evans et al. 2007). However, Williams et al. (2001) cite work in Europe suggesting migrating birds respond to coastlines, river systems, and mountains (e.g., Eastwood 1967, Bruderer 1978, 1999; Bruderer and Jenni 1988). While bird response to coastlines and major rivers has been noted in North America (e.g., Richardson 1978), evidence is limited on response to major changes in topography (Seilman et al. 1981, McCrary et al. 1983). Mabee et al. (2006) reported that for 952 flight paths of targets approaching a high mountain ridge along the Allegheny Front in West Virginia, the vast majority (90.5%) did not alter their flight direction while crossing the ridge. The remaining targets either shifted their flight direction by at least 10 degrees (8.9%) while crossing the ridge or turned and did not cross the ridge (0.6%), both of which were considered reactions to the ridgeline. This study suggests that only those birds flying at relatively low levels above the ground respond to changes in topography.

Although FAA lighting has been associated with increased avian fatalities at communications towers and other tall structures (Manville 2001, 2005, Erickson et al. 2001, Longcore et al. 2005, Rich and Longcore 2005), there is no evidence suggesting a lighting effect for wind power-associated passerine fatalities (Erickson et al. 2001b, P. Kerlinger, Curry and Kerlinger LLC, unpublished data). While steady-burning, red incandescent L-810 lights appear to be the major bird attractant to communications towers (Gehring et al. 2006), lighting at wind turbines tends to be red strobe or red-blinking/pulsating incandescent lighting (USFWS 2007). At the Mountaineer facility in West Virginia, Kerns and Kerlinger (2004) reported the largest avian fatality event at a wind facility, when 33 passerines were discovered on May 23, 2002. These fatalities apparently occurred just prior to the survey during heavy fog conditions; all carcasses were located at a substation and three adjacent turbines. The substation was brightly lit with sodium vapor lights. Following the discovery of these fatalities, the bright lights were turned off and no further major mortality events were documented during surveys at this site through fall 2003 (Kern and Kerlinger 2004) or during six weeks in the summer and fall of 2004 (Kerns et al. 2005).

Wind facilities located on forest ridges in the eastern U.S. have the highest documented bat and passerine fatalities. (Credit: Merlin D. Tuttle, Bat Conservation International)

Other Avian Species

Fatality studies almost universally report very few fatalities of waterfowl, shorebirds, or gallinaceous birds, as previously noted by Erickson et al. (2001). Kerlinger (2002) speculated that the upland sandpiper *(Bartramia longicauda)* might be at low to moderate risk of colliding with turbines, because of its aerial courtship flight. It has been documented that grouse are susceptible to powerlines and other structures. Borell (1939) reported greater sage-grouse *(Centrocercus urophasianus)* mortalities from powerlines, and 4 percent to 14 percent of greater prairie-chicken *(Tympanuchus cupido)* deaths in Wisconsin resulted from powerline strikes (Toepfer 2003). Wolfe et al. (2003) found that collisions with structures, fences, and vehicles by radio-collared lesser prairie-chickens *(Tympanuchus pallidicinctus)* accounted for 42 percent of the total mortalities, from a total of 122 recovered carcasses. They speculated that collision deaths could be additive to other mortality factors. In a review of five wind facilities, Fernley and Lowther (2006) reported that 1) collision of medium to large species of geese with wind turbines is an extremely rare event (unadjusted rates of 0–4/year for the 5 sites reviewed), 2) there appears to be no relationship between observed collision fatality and number of goose flights per year, and 3) geese appear to be adept at avoiding wind turbines.

Bats

Recent surveys have reported large numbers of bat fatalities at some wind energy facilities, especially in the eastern United States (e.g., Fiedler 2004, Kerns and Kerlinger 2004, Arnett 2005) and, more recently, in Canada (Brown and Hamilton 2006b) and New York (Jain et al. 2007). Relatively large numbers of bat fatalities at wind facilities also have been reported in Europe (Ahlen 2003, Dürr and Bach 2004, Brinkmann 2006). Although bats collide with other tall anthropogenic structures, the frequency and number of fatalities reported in the literature (e.g., Avery and Clement 1972, Crawford and Baker 1981, Mumford and Whitaker 1982) are much lower than those for birds or for bat fatalities observed at wind turbines.

Migratory, tree-roosting species like the hoary bat (Lasiurus cinereus) are most frequently found killed at wind facilities in North America (Credit: Ed Arnett, Bat Conservation International)

Several plausible hypotheses relating to possible sources of attraction, density and distribution of prey, and sensory failure (i.e., echolocation), for example, have been proposed to explain why bats are killed by wind turbines (Arnett 2005, Kunz et al. 2007a).

Estimates of bat fatality from 21 studies located at 19 different facilities from five different regions in the United States and one province in Canada ranged from 0.9–53.3 bats/MW (See table 2 on page 48); Arnett et al. 2008). These estimates vary due in part to region of study, habitat conditions, sampling interval, and bias corrections used to adjust estimates. Currently, forested ridges in the eastern United States have the documented highest fatalities of bats reported in North America and are higher than estimates of bat fatality reported from European studies (Dürr and Bach 2004, Brinkmann 2006).

Johnson (2005) and Arnett et al. (2008) recently synthesized existing information on bat fatalities at wind facilities; here, we summarize key patterns they identified. Bat fatality appears to be higher during late summer and early fall when bats typically begin autumn migration (Griffin 1970, Cryan 2003, Fleming and Eby 2003). Johnson (2005) reported that approximately 90 percent of 1,628 documented bat fatalities, when the approximate date of the collision was reported, occurred from mid-July through the end of September, with over 50 percent occurring in August. Collision fatality appears to be low during spring migration, but few studies have been conducted during this time period. Migratory tree bats may follow different migration routes in the spring and fall (Cryan 2003), and behavioral differences between migrating bats in the spring and fall also may be related to mortality patterns (Johnson 2005). Rarely have studies been conducted simultaneously at multiple sites within a region to evaluate seasonal patterns between sites. In 2004, Kerns et al. (2005) conducted daily fatality searches at the Mountaineer and Meyersdale Wind Energy Centers in West Virginia and Pennsylvania, respectively, and found that the timing of bat fatalities over a six-week period at the two sites was highly correlated (r = 0.8). Although Kerns at al. (2005) found more male than female fatalities, the timing of fatality by sex was similar at both sites, as well. Additionally, timing of fatalities of hoary *(Lasiurus cinereus)* and eastern red bats *(Lasiurus borealis)* was positively correlated between the Meyersdale and Mountaineer sites. These findings suggest broader landscape, perhaps regional, patterns of activity and migratory movement that could be influenced by weather and prey abundance and availability.

Eleven of the 45 species of bats that occur in North America north of Mexico have been among fatalities reported at wind facilities (Johnson 2005). Ten species of bats have been reported killed by turbines in Europe (Dürr and Bach 2004). In most regional and individual studies, bat fatalities appear heavily skewed to migratory foliage roosting species that include the hoary bat, eastern red bats, and migratory tree-roosting silver-haired bats (*Lasionycteris noctivagans*; Johnson 2005, Kunz et al. 2007, Arnett et al. 2007). In Europe, migratory species also dominate fatalities (Dürr and Bach 2004). Fatalities of eastern pipistrelles *(Pipistrellus subflavus)* have been reported as high as 25.4 percent of total fatalities at facilities in the eastern United States (Kerns et al. 2005). No studies have been reported from wooded ridges in the western United States and few from the southwest (e.g., New Mexico, Texas), where different species of bats may be more susceptible in some areas (e.g., Brazilian free-tailed bats [*Tadarida brasiliensis*]). Interestingly, the only two investigations at wind facilities within the range of the Brazilian free-tailed bat report high proportions of fatalities of that species (31.4 and 85.6% in California [Kerlinger et al. 2006] and Oklahoma [Piorkowski 2006], respectively). To date, no fatalities of a threatened or endangered species of bat (e.g., Indiana bat [*Myotis sodalis*]) have been found at existing wind facilities, but continued development of wind facilities may pose risk to these species at other locations in the future.

Spatial patterns of bat fatality and relationships between weather and turbine variables are poorly understood. Fatalities appear to be distributed across most or all turbines at wind facilities, with no discernable pattern of collisions reported to date. Bats do not appear to strike the turbine mast, non-moving blades, or meteorological towers (Arnett 2005). Horn et al. (2008) observed bats through thermal imaging cameras attempting to and actually landing on stationary blades and investigating turbine masts. They also reported that seven out of eight observed collisions were between bats and turbine blades spinning at their maximum rotational speed of 17 rpm. Activity and fatality of bats, as with birds, do not appear to be influenced by FAA lighting (Arnett 2005, Arnett et al. 2008).

Bat activity and fatality appear to be higher on nights with relatively low wind speed. Kerns et al. (2005) reported that the majority of bats were killed on low wind nights when power production appeared insubstantial (low percentage of total possible capacity generation), but turbine blades were still moving, often times at or close to full operational speed (17 rpm). The proportion of 10 min intervals from 2000–0600 hr when wind speed was <4 m/sec was positively related to bat fatalities ($r = 0.561$, $p < 0.001$ at Mountaineer; $r = 0.624$, $p < 0.001$ at Meyersdale), whereas the reverse was true for proportion of the night when winds were >6 m/sec ($r = -0.634$, $p < 0.001$ at Mountaineer; $r = -0.66$, $p < 0.001$ at Meyersdale). Horn et al. (2008) found a negative relationship between the number of bat passes observed from infrared thermal images and average nightly wind speed at the Mountaineer facility, corroborating the finding of higher bat fatalities on low wind nights at this facility. In Germany, Brinkmann (2006) observed higher activity of bats via thermal imaging when wind speeds were between 3.5 and 7.5 m/s, but also observed some activity up to 10.9 m/s. At Buffalo Mountain, Tennessee, Fiedler (2004) found a negative relationship between bat fatality and wind speed and temperature and a positive relationship with wind direction. The positive relationship with wind direction indicated that the farther nightly wind direction was from the Southwest (the prevailing wind direction), the more likely a fatality event was to occur, perhaps due to more northerly winds associated with storm fronts and/or conditions that are conducive for bat migration (Fiedler 2004). Fiedler (2004) also suggested that the presence of more northerly winds during nights with fatality may be related to weather conditions conducive for bat migration, and that negative associations with the other three variables imply that fatality occurrence was more likely during cooler nights with calmer, less variable winds. Acoustic monitoring of bats at proposed wind facilities corroborates these findings and indicates that bat activity generally is higher on low wind nights (Reynolds 2006; Arnett et al. 2006). Studies in Europe also corroborate these findings (Brinkman 2006). These observed patterns offer promise toward predicting periods of high fatality and warrant further investigation at wind facilities worldwide to assess whether these findings represent predictable, annual patterns.

WILDLIFE HABITAT IMPACTS AND DISTURBANCE AT WIND FACILITIES

Little is known about habitat impacts from development associated with wind facilities. Most permitting documents contain estimates of short- and long-term disturbance, but seldom include estimates of indirect impact. Additionally, efforts to follow up with post-construction estimates of actual impact are rare. Wildlife habitat impacts can be considered direct (e.g., vegetation removal and/or modification and physical landscape alteration, direct habitat loss) or indirect (e.g., behavioral response to wind facilities, hereinafter referred to as displacement or attraction). Impacts may be short-term (e.g., during construction and continuing through the period required for habitat restoration) and long-term (e.g., surface disturbance and chronic displacement effects for the life of the project). Duration of habitat impacts vary depending on the species of interest, the area impacted by the wind facility (including number of turbines), turbine size, vegetation and topography of the site, and climatic conditions in a particular region, which influences vegetation. Road construction, turbine pad construction, construction staging areas, installation of electrical substations, housing for control facilities, and transmission lines connecting the wind facility to the power grid also are potential sources of negative habitat impacts. Presence of wind turbines can alter the landscape so as to change habitat use patterns of wildlife, thereby displacing wildlife from areas near turbines. It is possible that audible noise from wind turbines can impact wildlife, but these effects are largely unknown.

Below, we synthesize what is known about habitat impacts from the few studies that have been conducted, draw inference from a broader literature on habitat impacts, and hypothesize potential impacts of wind turbines on wildlife.

Habitat Loss and Fragmentation

Wind facilities can cover relatively large areas (e.g., several square kilometers), but have relatively low direct impact to the project area. The BLM Programmatic Environmental Impact Statement (BLM 2005) estimated that the permanent footprint of a facility is 5 percent to 10 percent of the site, including turbines, roads, buildings, and transmission lines. This estimate was made for the more arid West and may differ for areas in the East, particularly in mountainous regions. Information on actual habitat loss was estimated from a review of permitting documents for 17 existing facilities or those under construction. The facilities ranged in size from 34 turbines (50 MW) at the proposed Chautauqua, New York, facility to the San Gorgonio, California, wind facility including more than 4,000 turbines of a variety of sizes. The total area of estimated impact ranged from 434 ha at the Foote Creek, Wyoming, wind plant to only 6.5 ha for the 16 turbine Buffalo Mountain, Tennessee, wind facility. In general, direct loss of habitat is relatively small, with the maximum surface disturbance of approximately 1.2 ha/turbine during construction (BLM 2005). However, a careful examination of the estimated direct impacts for the 17 facilities gave unrealistic, underestimated ranges of per turbine estimates of impact. For example, per turbine estimates of the size of permanent footprints for 1.5 MW turbines ranges from 1.4 ha for the proposed 34-turbine Chautauqua facility to 0.4 ha/turbine for the 120-turbine Desert Claim project in Kittitas County, Washington. While there appears to be some economy of scale for site impacts, the largest variable in all projects was length of new road construction.

Short-term construction surface disturbance has been estimated to be as much as three times the long-term surface disturbance, although short-term impacts for 17 permitting documents reviewed suggest that approximately 1.6 times the number of hectares of the permanent project footprint were affected. Construction impacts primarily result from wide construction rights of way to accommodate large cranes and, in mountainous terrain, the wide turning radius required to accommodate trucks hauling turbine blades in excess of 40 m. In addition, construction staging and equipment storage areas may be temporary disturbances. The length of time required to reclaim a site will vary depending on climate, vegetation, and reclamation objective. For example, if the objective is to return the site to pre-disturbance condition, reclamation may be relatively rapid in grassland, on the order of 2 to 3 years, versus de-

The presence of wind turbines can alter the landscape and may change habitat use patterns, thereby displacing some species of wildlife from areas near turbines. (Credit: Ed Arnett, Bat Conservation International)

Wind facilities located in habitats modified by agriculture will have fewer habitat impacts relative to those developed in undisturbed habitats. (Credit: Ed Arnett, Bat Conservation International).

Aerial perspective of structural habitat fragmentation due to oil, gas, and wind energy development within sand sagebrush (Artemesia filifolia) rangelands, Oklahoma. (Credit: D. Wolfe, G. M. Sutton Avian Research Center).

cades in desert environments.

Ultimately, the greatest habitat-related impact to wildlife may result from disturbance and avoidance of habitat. Because direct habitat loss appears to be relatively small for wind power projects, the degree to which this disturbance results in habitat fragmentation depends on the behavioral response of animals to turbines and human activity within the wind facility.

Habitat-Related Impacts on Birds

Grassland birds. Much attention regarding wind energy development and habitat fragmentation has focused on grassland birds for a number of reasons. First, North America's interior grassland habitats (tall, mixed, short, and sage) have steadily become more fragmented by a variety of human-induced influences (Samson and Knopf 1994, Knopf and Samson 1997). In many areas already fragmented by agriculture, the uncultivated grassland that remains exists on hilltops and in other locations that are difficult to plow but also have the greatest wind energy production potential (perhaps as much as 90 percent of the United States wind power potential [Weinberg and Williams 1990]). Second, among all bird groups, grassland birds have suffered population declines more consistently than any other suite of species, including Neotropical migrants (Droege and Sauer 1994), owing in part to the aforementioned habitat loss and fragmentation. Finally, of the three ecosystem types in the United States with greatest wind resources (Great Lakes, mountains, and grassland; Elliott et al. 1986), grassland habitats have the fewest logistical impediments to construction when transmission is available and currently have extensive wind energy development ongoing or planned (Weinberg and Williams 1990).

Relatively little work has been done to determine the effect of wind facilities on use of grasslands by birds. Here, we focus primarily on breeding birds, but recognize that it is likely that migrating and wintering birds may avoid wind facilities (Exo et al. 2003), although habitat for those activities is not suspected to be limiting or to influence population dynamics of grassland birds. In addition to the findings from studies of wind energy developments, we draw inferences from the larger body of literature on habitat fragmentation, which for grassland birds has grown considerably in the past decade (Johnson 2001).

Leddy et al. (1999) found that total breeding bird densities were lower in Conservation Reserve Program (CRP) fields with turbines compared with those without turbines in southwestern Minnesota. Moreover, densities of birds along transects increased with distance from turbines. While the extent of influence of turbines was uncertain, densities of birds were markedly lower within 80 m of the turbine string (Table 3; Leddy et al. 1999). Reduced avian use near turbines was attributed to avoidance of turbine noise and maintenance activities and reduced habitat effectiveness because of the presence of access roads and large gravel pads surrounding turbines (Leddy 1996; Johnson et al. 2000a). Other studies (e.g., Johnson et al. 2000b, Erickson et al. 2004) suggest that the area of influence of wind turbines is fairly small and that grassland birds occur in lower densities only within 100 m of a turbine. However, at a large wind facility at Buffalo Ridge, Minnesota, abundance of shorebirds, waterfowl, gallinaceous birds, woodpeckers, and several groups of passerines was significantly lower at survey plots with turbines compared with those without turbines (Johnson et al. 2000b). There were fewer differences in avian use as a function of distance from turbines, however, suggesting that the area of reduced use was limited primarily to those areas within 100 m of turbines (Johnson et al. 2000b). Some proportion of these displacement effects likely resulted from direct loss of habitat near the turbine from concrete pads and associated roads. These results are similar to those of Osborn et al. (2000), who reported that birds at Buffalo Ridge avoided flying in areas with turbines. Preliminary results from the Stateline (Oregon-Washington) wind facility suggest a fairly small-scale impact of the wind facility on grassland nesting passerines, with a large part of the impact related to direct loss of habitat from turbine pads and roads, and temporary disturbance of habitat between turbines and road shoulders (Erickson et al. 2004). Horned larks appeared least affected, with some suggestion of displacement for grasshopper sparrows *(Ammodramus savannarum),* although sample sizes were limited.

Research on habitat fragmentation has demonstrated that several species of grassland birds are area-sensitive, prefer larger patches of grassland, and tend to avoid trees. Area-sensitivity in grassland birds was reviewed by Johnson (2001); 13 species have been reported to favor larger patches of grassland in one or more studies. Other studies have reported an avoidance of trees by certain grassland bird species. Many of the studies refer to an avoidance of "edge," but edges in most studies consisted of woody vegetation. Seven grassland bird species have been shown to be edge-averse (Johnson 2001). Based on the available information, it is probable that some disturbance or displacement effects may occur to the grassland/shrub-steppe avian species occupying a site. The extent of these effects and their significance is unknown and hard to predict but could range from zero to several hundred meters.

Raptors. Development of wind turbines near raptor nests may result in indirect and direct impacts; however, the only report of avoidance of wind facilities by raptors occurred at Buffalo Ridge, where raptor nest density on 261 km^2 of land surrounding a wind facility was 5.94/100 km^2, yet no nests were present in the 32 km^2 wind facility itself, even though habitat was similar (Usgaard et al. 1997). Similar numbers of raptor nests were found before and after construction of Phase 1 of the Montezuma Hills, California, wind plant (Howell and Noone 1992). A pair of golden eagles *(Aquila chrysaetos)* successfully nested 0.8 km from the Foote Creek Rim, Wyoming, wind facility for three different years after it became operational (Johnson et al. 2000b), and a Swainson's hawk *(Buteo swainsoni)* nested within 0.8 km of a small wind plant in Oregon (Johnson et al. 2003a). In a survey to evaluate changes in nesting territory occupancy, Hunt and Hunt (2006) found that all 58 territories occupied by eagle pairs at APWRA in 2000 also were occupied in 2005.

Prairie grouse. 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. Serious population declines and the fact that prairie grouse distributions intersect with some of the continent's most prime wind generation regions (Weinberg and Williams 1990) compound the concern. Leks, the traditional courtship display grounds of greater sage-grouse, Gunnison's sage-grouse *(Centrocercus minimus)*, sharp-tailed grouse *(Tympanuchus phasianellus)*, lesser prairie-chicken, and greater prairie-chicken, are consistently located on elevated or flat grassland sites with few vertical obstructions (Flock 2002). Several studies indicate that prairie grouse strongly avoid certain anthropogenic features (e.g., roads, buildings, powerlines), resulting in sizable areas of habitat rendered less suitable (Braun et al. 2002, Robel et al. 2004, Pitman et al. 2005). Robel et al. (2004) observed mean avoidance buffers (mean distances based on 90% avoidance by 187 nesting hens) of 397 m (se = 70) from transmission lines, 93 m (se = 25) from oil or gas wellheads, 1,371 m (se = 65) from buildings, 336 m (se = 51) from center pivot irrigation fields, and 859 m (se = 44) from either side of improved roads (32 m (se = 15) from unimproved roads). Robel (2002) predicted that utility-scale (1.5 MW) wind turbines would create an approximate 1,600 m radius avoidance zone for greater prairie-chicken nesting and brood-rearing activities. Based on this estimate, they projected that a proposed 100 MW wind facility in the Flint Hills, Kansas, would render 6,070–7,280 ha of very good to excellent tallgrass prairie habitat unsuitable for nesting and brood-rearing purposes; the actual size of this proposed project was roughly half this area.

The widespread expansion of wind energy development, as is proposed in many ecologically intact areas of the Great Plains, could threaten already sensitive and declining species. The lesser prairie-chicken may best illustrate this onerous potential. The remaining habitat of this species overlaps almost entirely with areas identified as prime for wind generation in Oklahoma. If wind energy development expands into unbroken native and restored grasslands of the five states the species inhabits, increased negative impacts could be expected. In addition to loss of habitat as a result of abandonment, it is probable that wind development will negatively affect landscape structure. Declining grouse populations are strongly affected by broad spatial landscape changes (e.g., fragmenting and diminishing prairie chicken home ranges; Woodward et al. 2001, Fuhlendorf et al. 2002). Patten et al. (2005) suggested that landscape fragmentation would result in an expansion of home range size for greater prairie-chickens, likely resulting in decreased survivorship due to predation, collisions, and increased energy expenditures.

Other avian species. Estimated size of the mountain plover *(Charadrius montanus)*[2] population at the Foote Creek Rim wind facility declined from 1995 to 1999 during the wind facility construction period (1998 to 2000). It is not known if plovers were simply displaced from the rim because of construction activity or if the population declined, but declines recorded at a reference area and in other regional populations (southeast Wyoming – northeast Colorado) suggest a larger species-wide or regional phenomena coincidental to observations at Foote Creek Rim. In Europe, some species appear unaffected by the presence of wind turbines (Winkelman 1990), while certain waterfowl, shorebird, and songbird species are known to avoid turbines (e.g., European golden plovers [*Pluvialis apricaria*] and northern lapwings [*Vanellus vanellus*; Pederson and Poulsen 1991], Eurasian curlews [*Numenius arquata*; Winkelman 1990]). Spaans et al. (1998) suggested variable levels of disturbance for feeding and roosting birds and concluded that with the exception of lapwings, black-tailed godwits *(Limosa limosa)*, and redshanks *(Tringa tetanus)*, many species used areas for breeding that were close (within 100 m) to the wind facilities. Displacement effects of up to 600 m from wind turbines (reduced densities) have been recorded for some waterfowl species (e.g., pink-footed goose [*Anser brachyrhunchus*]; and European white-fronted goose [*Anser albifrons albifrons*]; Spaans et al. 1998). Larsen and Madsen (2000) found that avoidance distance of pink-footed geese from wind farms with turbines in lines and in clusters were estimated to be 100 m and 200 m, respectively. Low estimated waterfowl mortality at these sites may be due to the ability of waterfowl to avoid turbines, as suggested by Fernley and Lowther (2006). However, ability to avoid turbines may be related to weather conditions and availability of other suitable habitats. In Iowa, primary foraging habitat for geese (corn fields) is very common surrounding wind facilities, and no large-scale displacement of Canada geese *(Branta canadensis)* was apparent based on counts and behavior observations of geese in areas with and without turbines (Koford and Jain 2004).

David Young (Western Ecosystems Technology) studied mountain plovers at the Foote Creek Rim wind facility from 1995–1999. Declines of this species were reported at the wind facility, a reference area, and for other regional populations in southeast Wyoming and northeast Colorado, suggesting broader species-wide or regional phenomena coincidental to observations at Foote Creek Rim. (Credit: Fritz Knopf)

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[2] The U.S. Fish and Wildlife Service proposed listing mountain plover as a threatened species under the Endangered Species Act in February 1999 (USFWS 1999). Prior to this time, mountain plover had been included on the USFWS list of candidate species. In 2003, the USFWS found that listing mountain plover as threatened was not warranted and withdrew the proposed rule, stating that the threats to the species as identified are not as significant as earlier believed, and the plover is now not designated as a candidate species.

Habitat-Related Impacts on Bats

Unlike some forest-dependent species, bats may actually benefit from modifications to forest structure and the landscape resulting from construction of a wind facility. Bats are known to forage readily in small clearings (Grindal and Brigham 1998, Hayes 2003, Hayes and Loeb 2007) like those around turbines. Studies also have suggested that many species use linear landscape elements, such as those created by roads built through forest, for successful foraging or commuting (Grindal 1996, Russo et al. 2002, Patriquin and Barclay 2003), echo-orientation (Verboom et al. 1999) and protection from predators or wind (Verboom and Huitema 1997). Forest edge effects created by clearing also may be favorable to insect congregations and a bat's ability to capture them in flight (Verboom and Spoelstra 1999). Both local populations of bats as well as migrants making stopovers may be similarly attracted to these areas. However, the removal of roost trees would be detrimental to bats. Disturbance to tree- and crevice-roosting bats from wind turbines is completely unknown. It is not likely that noise generated by turbines influences roosting bats, but no empirical data exist to support or refute this contention. Increased human activity at wind facilities could disturb roosting bats, but, again, no data exist.

Habitat-Related Impacts on Large Mammals

Direct evidence of impacts on large mammals generally is lacking, and inferences are indirect based on disturbance from other anthropogenic sources. At western wind facilities located in native range, the species of concern are usually elk *(Cervus elaphis)*, mule deer *(Odocoileus hemionus)*, and pronghorn *(Antelocapra americanus)*. 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. Deficiencies in quality and/or quantity of habitat can lead to population declines. During the 9- to 12-month period of construction at a wind facility, it is expected that large mammals will be temporarily displaced from the site due to the influx of humans and heavy construction equipment and associated disturbance (e.g., blasting). Construction is rarely performed during winter, thus minimizing construction disturbance to wintering ungulates. Following completion of a project, disturbance levels from construction equipment and humans diminish, and the primary disturbances will be associated with operations and maintenance personnel, occasional vehicular traffic, and presence of turbines and other facilities.

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 important. The impacts of habitat loss and fragmentation are greatest when habitat is in short supply. Roads associated with energy development also may fragment otherwise continuous patches of suitable habitat, effectively decreasing the amount of winter range, for example, available for ungulates. Fragmentation of habitat also may limit the ability of ungulate populations to move throughout winter range as conditions change, causing animals to utilize less suitable habitat (Brown 1992). At the Foote Creek Rim facility in Wyoming, pronghorn observed during raptor use surveys were recorded year-round before and after construction (Johnson et. al. 2000) and results indicated no reduction in use of the immediate 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 is concern that development of wind power in the northeastern United States on forested ridge tops, in stands of mast-producing hardwoods, and in wetlands will have a negative impact on black bears. In the state's wind policy, the Vermont wildlife agency expresses this concern, but notes that negative impacts have not yet been documented. Perhaps the greatest potential for impact is disturbance of denning black bears. In a review of the literature on den site selection, Linnell et al. (2000) found that black bears generally select dens 1–2 km from human activity (roads, habitation, industrial activity) and seemed to tolerate most activities that occurred >1 km from the den. Activity <1 km and especially within 200 m caused variable responses, including den abandonment. While the loss of a single den site may not lead to deleterious effects, den abandonment can lead to increased cub mortality (Linnell et al. 2000).

While the footprint of wind facilities is relatively small, if the facilities are placed in critical habitat areas, the direct loss of habitat would be a negative for large mammals. Additionally, studies on the impacts of oil and gas developments on ungulates suggest shifts in use, avoidance of roads, and potential declines in reproduction and abundance (Van Dyke and Klein 1996, Sawyer et al. 2006). Studies of mule deer and elk in Oregon suggest that habitat selection and movements may be altered by roads, primarily because of the associated human activities (Johnson et al. 2000, Wisdom et al. 2004). 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.

Habitat-Related Impacts on Other Wildlife

Virtually nothing is known about habitat-related impacts on other species of wildlife, including reptiles, amphibians, forest carnivores, and small mammals. In a study addressing the influence of audible noise from turbines on predator strategies employed by California ground squirrels *(Spermophilus beecheyi)* at Altamont Pass, Rabin et al. (2006) reported that this species may be able to cope with noise from wind turbines through behavioral modifications in a predatory context. While inferences about potential habitat impacts from wind facilities on other wildlife could be drawn from data on other sources of disturbance, more studies would be useful for understanding and mitigating these potential impacts for other species.

OFFSHORE WILDLIFE—WIND ISSUES

Interest is high in establishing wind-generating facilities along portions of the Atlantic Coast, Lower Gulf Coast (LGC) of Texas, and the Great Lakes. Terrain offshore (coastal shelf) in these areas is shallow for a relatively long distance from shore, which permits placement of towers into the bottom substrate with existing technology. The first major wind-energy development proposed for the Atlantic Coast is located in Nantucket Sound, Massachusetts (Cape Wind Project). This project met with opposition from several groups, including those concerned with potential impacts to local fauna and the lack of studies on the movements of birds through the project area. In 2005, the State of Texas began steps for permitting the first commercial offshore wind-energy development, planned for a location off Galveston Island.

Although studies seem to indicate that wind facilities in some locations of the United States have a minor impact on birds compared to other sources of collision mortality, one cannot assume that similar impacts would occur among birds using wind-generating sites established offshore. As with land-based wind development, offshore development must also address cumulative impacts to birds, bats, and marine resources.

Offshore Bird Movements and Behavior

Three migratory bird corridors converge immediately north of Corpus Christi, Texas, effectively funneling tens of millions of birds along the LGC to wintering grounds in south Texas and Latin America. Over 200 species of birds migrate along the LGC in Texas annually and several federally threatened or endangered species are included among these. The largest numbers of migrating birds cross the Gulf of Mexico from the northern Texas coast, eastward to the Florida panhandle (Figure 4). Crossing the Gulf represents the shortest route to extreme southeast Mexico for some migrants, while birds migrating along the LGC tend to follow the coastline because of its primary north-south orientation, rendering crossing the Gulf relatively less important (Figure 4, route 5; Lincoln et al. 1998).

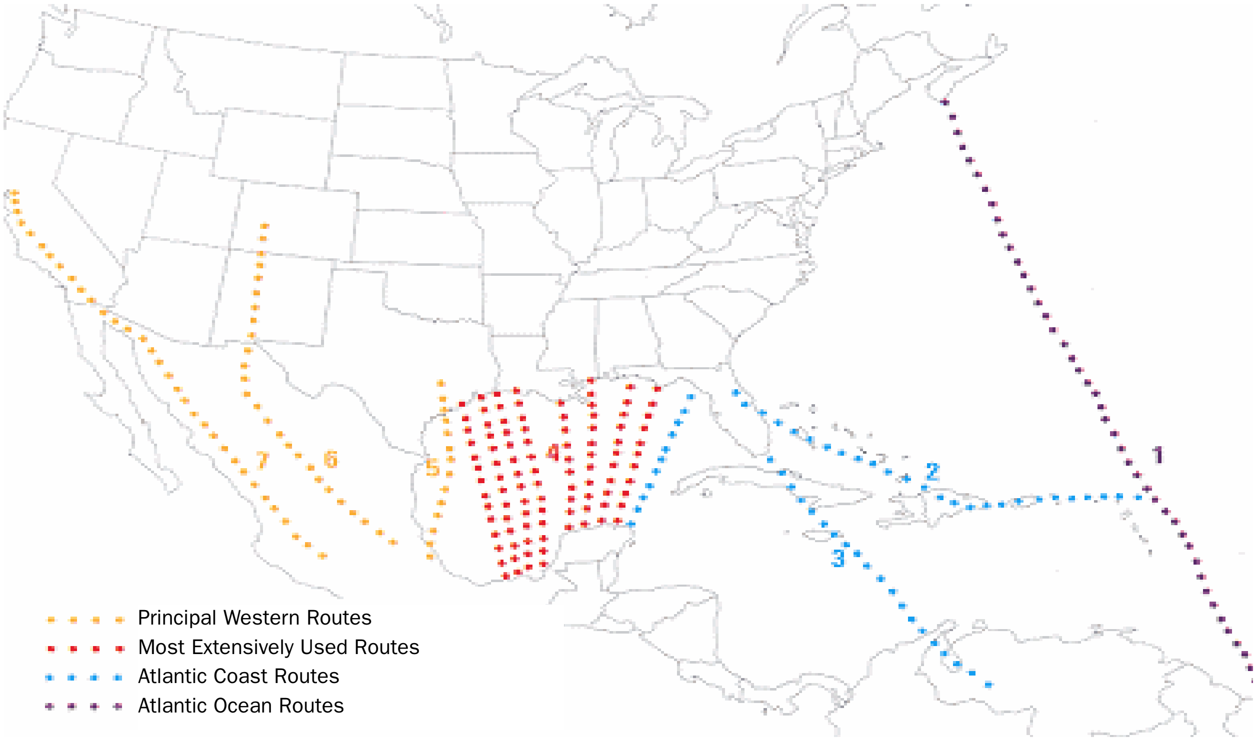
One of the most important components of avian migration strategies is their use of local habitats for resting and refueling while en route. In light of the absence of natural islands or other terrestrial habitats in the Gulf of Mexico, it seems inevitable that the installation of thousands of artificial islands in the northern Gulf must affect migrants in some fashion. However, few systematic studies have examined the influence of Gulf oil platforms on trans-Gulf migrating birds. From 1998–2000, Russell (2005) studied the ecology of trans-Gulf migration and the influence of platforms and showed that most spring trans-Gulf migration detected by radar occurred between 25 March and 24 May, but very large flights (>25 million migrants) occurred only in the three-week period from 22 April to 13 May. Waterfowl and herons peaked by early

April and shorebirds had widely varying migration schedules, with different species peaking as early as mid-March and as late as the end of May. Landbird migrants showed peaks throughout the season, but a majority of species peaked in the second half of April. Theoretical analyses of radar data yielded total seasonal estimates of 316 million trans-Gulf migrants in spring 1998 and 147 million trans-Gulf migrants in spring 1999. Radar-observed spring migration was characterized by a series of pulses and tended to be "all-or-nothing"; that is, either significant trans-Gulf migration was evident on radar or else it was essentially entirely absent. Dramatic hiatuses in radar-observed migration were always associated with strong cold fronts that penetrated deep into Mexico and set up persistent northerly winds over most of the Gulf (Russell 2005). Studies such as that of Russell (2005) indicate that potential exists for interactions between a substantial number of migrant birds and offshore and near-shore wind turbines.

Although Neotropical migrant birds do pass offshore along the Atlantic Coast (Figure 4), the magnitude of migration is small relative to that along the Gulf Coast. Concern along the Atlantic Coast is focused more on potential impacts to waterbirds such as gulls, terns, waterfowl, and other species that make regular movements in near-shore areas. There are many "Important Bird Areas," locations that harbor a high number of birds or species of special concern (e.g., Federally designated Birds of Conservation Concern and Federally listed threatened or endangered birds), along the eastern seaboard. Although areas where birds migrate through or concentrate seasonal activities are generally known, the specific timing, routes, and altitudes of movement within and between resting and foraging areas and altitudes that migrants use are poorly known, and such information is needed to conduct assessments of the potential risk of to birds from offshore wind developments.

Consequently, impacts of a wind-generating facility located on the LGC and Atlantic Coast could be different from each other and also different than those located at other sites throughout the United States simply because the behavior, abundance and diversity of birds that migrate or reside on any wind-generating facility site may be much different than at inland facilities. Russell (2005) found that migrants would sometimes arrive at certain oil platforms

Figure 4. Primary migratory routes of birds (from Lincoln et al. 1998).



shortly after nightfall and proceed to circle those platforms for variable periods ranging from minutes to hours. The numbers of birds involved varied from a single individual to many hundreds of migrants and, while a wide variety of species was recorded in circulations, herons, shorebirds, swallows, and warblers were most common. This behavior, if repeated around offshore wind turbines, could raise the risk of collision with the tower or the blade. Russell (2005) concluded that this circling behavior was related to attraction of the birds to platform lights. Many offshore developments have proposed turbine-tower combinations that are near or exceed 160 m in total height, making them highly visible from several km away. In some locations, aircraft warning lights may be required by the FAA, which adds another dimension to visual considerations.

Offshore Impacts on Habitat and Animal Movements

Offshore wind facilities have been established throughout Europe, but few studies have been conducted to determine impact on animals. Most of these developments are small relative to onshore developments (although larger projects are being planned). Some disruption in bird flight patterns has been noted in Europe, although additional study is needed. However, there does not appear to be disruption in fish movements or populations (Morrison 2006). The effects on marine mammals warrant study and clarification, especially since most great whales are federally listed. A major concern with offshore developments relates to impacts on animal behavior and movement from boat and helicopter traffic to and from the wind development that could extend far outside the boundaries of the turbines.

European Studies

More than 280 studies have been conducted relating environmental and human effects from offshore wind installations in Europe. There have been, however, concerns about the adequacy of these studies because most projects had few turbines (less than 10), did not employ rigorous study design, and were not peer-reviewed. To address uncertainty from past studies, two major projects were developed: Concerted Action for the Offshore Wind Energy in Europe (CA-OWEE) and Concerted Action for the Deployment of Offshore Wind (COD). In 2005, COD compiled available studies in a searchable electronic database and summarized its findings in a final report: "The COD work on the establishment of an environmental body of experience has brought an important overview of the present state of knowledge in this up-to-now unknown field" (COD 2005, 2).[3] Two Greenpeace International reports summarized environmental impact assessment studies in Europe prepared by Deutsches Windenergie Institute (2000) and Deutsche WindGuard GmbH (2005), respectively.[4]

These reports suggest that major risks from offshore wind turbines to sea birds and resting birds are:

- Permanent loss of habitat due to displacement;
- Collisions with the turbines; and
- Barrier effects, including fragmentation of the ecological habitat network (e.g., breeding or feeding areas).

Of these, collisions and disturbance were considered primary impacts on sea birds and resting birds, although these groups may be at less risk than migrating birds, as they may adapt better to offshore wind facilities (COD 2005). Large offshore wind facilities may diminish foraging and resting conditions and so assessment of cumulative effects is needed. Thus far, risks of habitat loss and barrier effects for birds have not been quantitatively estimated. Avoidance behavior of birds is significant in evaluating these risks; species-specific avoidance behavior and overall availability of suitable areas are important considerations when evaluating impacts.

Collisions of birds with wind turbines at offshore wind facilities, in most cases, are only a minor problem (but with exceptions in some poorly sited land-based facilities [Greenpeace International 2000, section 5.3.3]). Quantitative risk estimates for collision risks are difficult to obtain due to the fact that impacts are highly site-dependent, inadequate data exist on bird migration routes and flight behavior

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[3] See the CA-OWEE and COD reports and database at www.offshorewindenergy.org. See the summary in "COD, Principal Findings 2003-2005," prepared by SenterNovem in the Netherlands, as part of a series highlighting the potential for innovative non-nuclear energy technologies.

[4] See "Offshore Wind: Implementing a New Powerhouse for Europe; Grid Connection, Environmental Impact, Assessment, Political Framework," 4 April 2005, WindGuard GmbH, commissioned by Greenpeace, at http://www.greenpeace.org/international/press/reports/offshore-wind-implementing-a and "North Sea Offshore Wind—A Powerhouse for Europe; Technical Possibilities and Ecological Consideration," 2000.

(Exo et al. 2003), impacts vary for different bird species, measurements address only found bird corpses, and results thus far are often contradictory between studies (Desholm and Kahlert 2005). Winkelman (1994) provides an overview of research carried out in Europe with special emphasis on results of the two most in-depth studies (Winkelman 1992, parts 1-4). At 108 sites, 303 dead birds were found, of which at least 41 percent were proven collision deaths. Of 14 collisions visually observed, 43 percent were caused by birds swept down by the wake behind a rotor, 36 percent by a rotor, and 21 percent unknown. The author states that total numbers likely to be killed per 1,000 MW of wind power capacity are low relative to other human-related causes of death. Because fewer birds probably collided with the middle row of wind turbines, Winkelman (1992) suggested that a cluster formation of turbines may cause fewer impacts than a line formation. Lighting of wind turbines was believed to be harmful rather than beneficial, particularly when weather and visibility are bad (Winkelman 1992, 1994). Still, a number of studies conducted thus far at offshore facilities suggest little or no impact on bird life (COD 2001). A recent study of 1.5 million migrating seabirds from Swedish wind facilities in Kalmarsund concluded that fatality risk to passing seabirds was only one in 100,000 (Eriksson and Petersson 2005). In Denmark, radar studies indicate that migrating birds avoid flying through the Nysted wind facility. These studies reveal that 35 percent of the birds fly through the area at baseline, but only 9 percent after construction. Monitoring at the operating Horns Rev wind facility in Denmark found that, "…most bird species generally exhibit an avoidance reduction to the wind turbines, which reduces the probability of collisions" (Elsam Engineering and ENERGI E2 2005). From the European point of view, in most circumstances disturbance and habitat loss are thought to be of much more importance than bird mortality, although the consequences on populations remain unknown.

Winkelman (1994) also summarized findings on disturbance and effect of turbines on flight behavior, which were investigated in most studies. Up to a 95 percent reduction in bird numbers has been shown to occur in the disturbance zones (250–500 m from the nearest turbines). Winkelman (1985) studied the possible danger to birds of medium-sized wind turbines (tower height 10–30 m) situated on six small wind facilities located along or near the Dutch coast and reported that diurnal migrants seemed to respond more to operating turbines than did local birds. An average of 13 percent of migrating flocks and 5 percent of local flights showed a change in flight behavior that could be attributed to the turbines during this study, suggesting that local birds may habituate to wind turbines. Fox and Nilsson (2005) summarized results from offshore radar studies in Denmark and Sweden, respectively, and reported marked seaduck avoidance of existing wind facilities ("Offshore and Nearshore Wind Development, and Impacts to Sea Ducks and Other Waterbirds," 2nd N. Am. Sea Duck Conference, Annapolis, MD, 2005; results on USGS-Patuxent Wildlife Research Area website). Winkelman (1990) studied behavior of birds approaching wind turbines during day and night conditions and found that 92 percent of birds approached the rotor without any hesitation during the day compared to 43 percent at night. During high-use nights, Winkelman (1990) found that 56 percent to 70 percent of the birds passed at rotor height (21–50 m) and more birds collided with the rotor at night and twilight than during the day. Of 51 birds recorded trying to cross the rotor area during twilight and total darkness, 14 (28%) collided while only one of 14 birds (7%) collided, during the day. Based on the number of birds passing at rotor height and the proportion of birds colliding, Winkelman (1990) estimated 1 out of 76 birds passing the towers at night was expected to collide with turbines when the facility was fully operational.

Following Winkelman's (1994) review, Exo et al. (2003) reviewed the status of offshore wind-energy developments and research on birds in Europe and noted that European seas are internationally important for a number of breeding and resting seabird populations that are subject to special protection status. Moreover, every year tens of millions of birds cross the North Sea and the Baltic Sea on migration. They concluded the erection of offshore wind turbines may affect birds as follows: (1) risk of collision; (2) short-term habitat loss during construction; (3) long-term habitat loss due to disturbance by turbines, including disturbances from boating activities in connection with maintenance; (4) formation of barriers on migration routes; and (5) disconnection of ecological units, such as between roosting and feeding sites. These researchers also stated it was vital that all potential construction sites are considered as part of an integral assessment framework, so that cumulative effects can be fully taken into account. They concluded, however, that making these assessments was hindered by a lack of good data on migration routes and flight behavior of many of the relevant bird species. They added that, based on experience gained from studies at inland wind facilities and at the near-shore sites where environmental impact assessments are currently under way, marine wind facilities could have a significant adverse effect on resident seabirds and other coastal birds as well as migrants. Moreover, the potential impacts may be considerably higher offshore than onshore. Disturbance and barrier effects probably constitute the highest conflict potential (Exo et al. 2003). While further studies are needed to better define the risks, precautionary measures to reduce and mitigate such risks exist. For example, careful siting of wind facilities away from bird migratory paths, bird habitats, and large concentrations of species at higher risk is possible.

ISSUES REGARDING STUDIES ON WIND ENERGY AND WILDLIFE

The location of a wind facility can be critically important based on its known, suspected, or potential impacts on wildlife and their habitats. By performing risk evaluations and pre-construction monitoring, potential impacts could be predicted and potentially avoided or mitigated. Post-construction evaluations, in turn, can validate (or negate) hypotheses, conclusions, and assumptions reached from risk evaluations and pre-construction monitoring performed before the project is actually built. Post-construction monitoring also provides data allowing “mid-course corrections” to respond to problems discovered by monitoring through subsequent use of deterrents (although no deterrents of proven effectiveness are currently available), mitigation, or alternative actions and can assist in the permitting and design of future facilities.

Peer Review and Publication

Currently, few studies of wildlife interactions with wind turbines have been published in refereed scientific journals, although this trend is changing. Most reports on wind-wildlife relationships have entered the “gray literature” and appear on the Internet, possibly accompanied by archived paper copies. Many others are retained by wind energy companies as proprietary material not available to outside parties, including regulatory agencies. We believe that peer review lends some credibility to “gray literature” even if a document is never published as a stand-alone paper in a scientific journal, but strongly encourage publication in journals. Peer review is an integral component of scientific research and publishing and an important means of ensuring sound information (The Wildlifer May-June 2006). The shortage of scientific publication on wind-wildlife interactions (GAO 2005, Kunz et al. 2007a) must be overcome to place the problem on a base of solid science.

Study Design and Duration

Investigations of wind turbine and wildlife interactions and impacts are relatively recent and there is a dearth of information upon which to base decisions. With few exceptions, most work conducted to date has been short-term (e.g., only one field season) and the frequency of study (e.g., both season length and time into the night at which research is conducted) also may be inadequate. Longer-term studies are required to elucidate patterns, better estimate fatality, and develop predictive models to estimate the risk of fatalities and evaluate possible habitat fragmentation or other disturbance effects. As one example, birds may continue to occupy habitats suddenly rendered unsuitable because of some “inertia” (Wiens et al. 1986). If that occurs, an unsuitable site will continue to support birds for several years, and a short-term evaluation will not identify effects of the treatment. Another example: some disturbance to the vegetation caused by construction might induce short-term effects that will diminish over time. For these reasons, it is desirable to monitor wind facilities for several years after construction. Years need not always be consecutive, although conducting studies in alternate years may pose budgeting difficulties. The British Government, for example, requires three to five years of post-construction monitoring on offshore projects constructed on Crown lands (DEFRA 2005).

Because randomization of "treatments" (installation of wind turbines) is not feasible, true experimentation is impossible. Before-After, Control-Impact (BACI) studies are the next best approach (Stewart-Oaten et al. 1986, Smith 2002), along with impact gradient studies in some cases (e.g., where habitats are homogeneous or where before data are unavailable). Some guidelines for conducting such studies have been developed recently (Anderson et al. 1999, Erickson et al. 2005), but these need to be modified to accommodate each particular site. Acquiring data on wildlife use at a site before construction begins is essential to account for variation in populations among sites. Collecting site-specific pre-construction data can be complicated when exact locations of wind turbines are not identified or divulged far enough in advance of construction to allow time to design and conduct monitoring. Data from reference sites without wind turbines improves understanding of potential cause and effect relationships, particularly where variation among years is common, such as in grassland bird populations, for example. In some situations, however, it is difficult to find sites that are similar in location, topography, vegetation, and land use, and which themselves are not sites of wind turbines.

Metrics and methods guidance document. Anderson et al. (1999) prepared a document for the National Wind Coordinating Committee (see www.nwcc.org) titled "Studying Wind Energy/Bird Interactions: a Guidance Document:Metrics and Methods for Determining or Monitoring Potential Impacts on Birds at Existing and Proposed Wind Energy Sites." This document contains detailed standardized metrics and methods for performing various studies, observations, and evaluations of the impact of wind energy facilities on wildlife. Anderson et al. (1999) present efficient, cost-effective study designs intended to produce similar types of data for comparison among projects, which could potentially reduce the need for detailed surveys or research at other proposed projects in the future. Specifically, the Metrics and Methods Document identifies four levels of surveys, which at the time the document was published were designed primarily for avian studies. They include:

1) "Site evaluation," where information is collected from existing sources including local expertise, literature searches, natural resource databases, lists of state and federally listed species and critical habitats, reconnaissance surveys of the site, vegetation mapping, and an assessment if information available is sufficient to make a defensible determination to build or not build at the site. These "evaluations" generally are not highly rigorous, as they are typically used to screen sites, although they may need to be if federally or state-listed species are present, or species susceptible to collisions or disturbance are present.

2) "Level 1 studies" include pre-permitting baseline studies, risk assessment studies, and monitoring studies designed to detect relatively large effects of operating wind facilities on wildlife. A BACI Design may also be used as part of a "level 1 study" since it may help answer the question, "did the average difference in abundance between the [control] area(s) and the wind plant area change after the construction and operation?" (Anderson et al. 1999:25). Meta-analysis, an approach to combining statistical results from several independent studies all dealing with the same issue, is also suggested as a tool for "level 1 studies."

3) "Level 2 studies" involve detailed studies of one or more populations, manipulative studies designed to determine mechanisms involved in fatality and risk, the quantification of risk to populations, and the evaluation of risk-reduction management practices.

4) "Risk-reduction studies" attempt to assess attributable risk versus preventable risk to avian populations; review suggestions for measuring risk; include counts for bird utilization, mortality, scavenger removal, and observer bias; and review the challenges addressing indirect interactions affecting "habitat" and "vegetation type."

In addition to research protocols suggested in the Metrics and Methods document, regulatory agencies also examine and may recommend other protocols (e.g., "best management practices" suggested by the BLM, suggestions from the Government of Great Britain in its regulatory offshore wind development [DEFRA 2005]), and specific recommendations from USFWS in its voluntary guidance to avoid and minimize impacts to wildlife and habitats [USFWS 2003]).

Inconsistent Methodology and Implementation

One problem with site review and evaluation is inconsistent implementation of procedures to assess impact and risk, and to perform pre-, during- and post-construction evaluation and monitoring. Some assessments are performed at minimal levels of evaluation while others at sites with an apparent comparable level of risk are performed in much more rigorous, scientifically valid ways. Use of standardized protocols to address specific questions would improve comparability of studies and credibility of efforts. Consistency would greatly assist regulatory agencies during decision making in regard to statutory trust responsibilities. However, state permitting processes vary widely in regard to environmental requirements, thus potentially hindering consistent development of objectives and implementation of methodologies. On private lands or where no federal nexus exists, federal agencies can only suggest which protocols might be used and to what extent.

Assessing the overall impact of a wind project is prudent and such broad assessments should include potential impacts such as collision mortality, indirect impacts from reduced nesting and breeding densities, habitat and site abandonment, loss of refugia, displacement to less-suitable habitats, effects on behavior of wildlife, changes in resource availability, disturbance, avoidance, fragmentation, and an assessment of cumulative impact. Unfortunately, indirect effects often are very difficult to predict. Inadequate or no impact assessments are problematic. For example, “risk assessments” performed for bats at Buffalo Mountain, Tennessee, Mountaineer, West Virginia, and Meyersdale, Pennsylvania, did not identify high risk (at least to non-federally listed bats; e.g., hoary and red bats), but later were documented to have the highest bat kills ever recorded at a wind facility (Arnett et al. 2008). While no formal “risk assessment” process was conducted at APWRA, California, USFWS biologists and other agency biologists and managers advised proponents in the late 1980s and early 1990s of potential problems, but these concerns have not been successfully addressed even though high levels of raptor mortality have been documented. Pre-construction estimation of such events and potential impacts requires more extensive study at both existing and proposed wind facilities. These broader assessments, while daunting, will be critical for understanding not only the potential impacts, but also development of solutions.

Technological Tools for Studying Wind-Wildlife Interactions

Numerous technological tools exist for conducting pre-construction assessments and predicting both direct and indirect impacts of wind facilities on wildlife (see Anderson et al. 1999 and Kunz et al. 2007b for detailed reviews). Here, we focus on remote sensing technologies that employ radar, thermal infrared imaging, and acoustic detection, but also recognize that other techniques exist to study wind-wildlife interactions (e.g., night vision, mist-netting, radio telemetry). No single method can be used unambiguously for assessing temporal and spatial variation in natural populations or the impacts of wind turbines on bats and nocturnally active birds. Employing a combination of techniques, including night vision observations, reflectance and thermal infrared imaging, marine radar, NEXRAD Doppler radar, and captures can contribute most toward understanding how bats and birds may be impacted by wind energy developments (Kunz et al. 2007b). Each device or method has its own strengths, limitations, and biases and it is essential for field researchers to understand these limitations and ensure that the fundamentals of study design and sampling (e.g., Anderson et al. 1999, Morrison et al. 2001) are employed and sufficient data are gathered to address the question of interest.

Radar is a broadly-applicable technique for observing flying animals (most radar systems are unable to distinguish individual “targets” or differentiate between birds and bats and insects) and is a widely used tool during pre-construction assessments at proposed wind facilities. Recent reviews by Bruderer (1997a, b), Diehl (2005), and Larkin (2005), as well as the classic text by Eastwood (1967), describe how various kinds of radar operate and their use in wildlife research and monitoring. With regard to wind energy facilities, radar has a role in broad-scale surveys of migratory and roosting movements of flying animals, pre-construction monitoring of proposed sites for wind facilities, and post-construction observation of the behavior of flying animals approaching fields of wind turbines and around individual turbines, and for estimating exposure for use in the analysis of bird and bat fatalities. Appropriate use of radar occupies a prominent position in the available tools because it can report the three-dimensional position of echo-producing objects ("targets"), operates day and night, can detect flying biota beyond the range of most other techniques, can be used freely in conjunction with other techniques such as light- and infrared-based observation, and does not affect the behavior of the animals being observed (Bruderer 1999).

Some kinds of radar data are relatively inexpensive to acquire. The long reach of the equipment and continuous, perhaps even unattended, operation appear ideal for quick surveys of the airborne biota. In the present climate favoring installing wind turbines quickly and the scarcity of funding for research on the machines' effects on wildlife, radar offers a powerful tool, yet decision-makers may be asked to accept radar data out of context and inappropriately. Those considering using radar should be aware of three possibly critical deficiencies:

- **Height (geometry).** Flying animals significantly above or below the rotor-swept area of turbines are probably in little danger. Therefore, surveys of local and migrating flying animals must document how they are distributed vertically. No radar can provide accurate height information at long range, and marine radar mounted in the conventional fashion cannot provide accurate height information.
- **Metal rotor blades.** Radar cannot be used to observe flying animals close to large, metal-containing, moving objects such as blades of wind turbines. "Close" is defined in terms of the resolution (pulse volume) of the radar when sited near a wind turbine. This disadvantage may be unimportant when studying only animals approaching a wind facility or a turbine rather than actually interacting with turbine blades.
- **Distinguishing targets.** A migrating bat may be orders of magnitude more vulnerable to wind turbines than a bird flying nearby, but the flying mammal and bird may present identical-appearing and -moving echoes on most radars. Even the mass of flying animals is only loosely related to body size (Vaughn 1985). This is part of a larger problem of detection bias that includes bias as a function of distance, interaction of targets (e.g., interpretation of intersecting targets), the determination of the actual space sampled by the radar, and the effect of weather and topography. Ongoing research is attempting to use optical techniques to provide taxonomic information when radar is being used.

Thermal Infrared (TI) cameras sense metabolic heat emitted by animals in flight, producing a clear image against the cooler sky and landscape without need for artificial illumination that may disturb normal behavior (Kunz et al. 2007b). Digital images are captured at variable rates up to 100 frames per second and recorded to disk, thus achieving high temporal detail for extended periods. TI may be useful for post-construction research. Horn et al. 2008 demonstrated that bats were more frequently observed in the vicinity of sampled turbines on forested mountain ridges during periods of low wind. Bats were observed striking various regions along the blade, approaching non-moving blades, and investigating the structure with repeated fly-bys, sometimes briefly alighting or landing on them. Small size and portability facilitate use of TI in the field, but monitoring turbines is challenged by finding a compromise between viewable area and resolution. A station may consist of a single high-resolution camera or an array of several lower-resolution cameras to achieve the same resolving power and viewable area. Multiple cameras with large field-of-view can be positioned close to turbines, improving image clarity and, during later analysis, permitting stereo estimation of distances and 3D reconstruction of flight paths. Collection of TI images currently is limited by availability of equipment, the need for large amounts of data storage, and costs of equipment and analysis of data.

Acoustic monitoring allows researchers to detect and record various calls of echolocating bats and vocalizing birds that can be used to assess relative activity and identify species or groups of species, which applies to both pre- and post-construction studies. Acoustic methods have several limitations. Detection is only possible when birds are calling or bats are echolocating within the range of the detectors, and factors influencing detection probability remain poorly understood. The method can only be used to indicate presence, but not absence. Pre-construction monitoring of vocalizations to identify sites with high levels of bird and bat activity or use by sensitive species prior to construction may be valuable in assessment of site-specific risks of turbine construction to birds and bats (Kunz et al. 2007b). A key assumption is that pre-construction activity, as estimated through vocalizations, is correlated with post-construction bird and bat mortality, yet we are currently unaware of any study linking pre-construction monitoring data with post-construction fatality, although such efforts are under way (e.g., Arnett et al. 2006). Acoustic detectors often are used in the field without a thorough understanding of underlying assumptions and limitations or standardized protocols (Hayes 2000, Weller and Zabel 2002, Gannon et al. 2003). Although echolocation calls are reliably distinguishable from other sounds (e.g., bird, arthropod, wind, mechanical), the ability to distinguish species of bats varies with taxon, location, type of equipment, and quality of recording, and may be challenging. Estimating amount of activity of those bats echolocating is straightforward, but estimating abundance requires differentiation between multiple passes of a single bat and multiple bats making single passes and is not usually possible.

RESEARCH NEEDS

Along with providing a framework for development of more robust experimental field design, use of accepted standardized protocols will greatly enhance researchers' ability to compare and analyze data among studies from various facilities. More important than interpreting results from individual studies is the search for consistent patterns ("metareplication," sensu Johnson 2002). What patterns are consistent, and what variation in patterns occurs among species, habitat types, and geographic locations? The effect of changing technologies (e.g., bigger turbines) on bird and bat fatalities should be investigated. Predictions of future impacts will necessarily be based on today's technology, but it is important that we understand how changing technology may affect those predictions. There also is the need to determine effectiveness of mitigation measures currently in use (e.g., turbine placement) and develop and evaluate new mitigation measures. It is important that a better understanding of the influence of wind facilities on wildlife and their habitats be sought and, to that end, studies should be undertaken at wind facilities and reference sites both before and after construction. Short-term studies may not identify potentially deleterious impacts of wind facilities or efficacy of mitigation. Longer-term and broader assessments of cumulative impacts and potential mitigation strategies are clearly warranted. The dearth of available information regarding impacts of wind development on wildlife creates uncertainty that should be addressed in an adaptive management context (Walters 1986, Walters and Holling 1990) until proven solutions to wildlife fatalities and habitat-related impacts are found. As new information becomes available, data should be used to trigger adjustments to mitigation strategies that reduce impacts on wildlife. Decision-making frameworks will be required to establish what data are required and how they will be used to establish triggers and thresholds for adjusting strategies for mitigating wildlife impacts.

Based on our review, we offer the following suggestions for priority research needed to elucidate patterns of fatality, evaluate the context and biological and population implications, determine risk to predict future impacts, develop mitigation strategies, and assess efficacy of methods and tools used to study impacts of wind energy development on wildlife and their habitats. Our suggestions are not exhaustive, but reflect our view of high-priority needs to advance our knowledge and develop effective mitigation strategies for the responsible development of wind energy.

Birds and Bats

Numerous questions require further and immediate investigation to advance the understanding of bird and bat fatalities at wind turbines, develop solutions for existing facilities, and aid with assessing risk at future wind facilities. First there needs to be a better synthesis of existing information. A priority research need for existing wind facilities is an estimate of impacts, both fatalities and habitat-related impacts for facilities located in unstudied or new locations (e.g., eastern mountains, the Southwest, coastal, offshore). Determining numbers of individuals, for both birds and bats, and their exposure to risk at turbines, is critical for developing a context upon which to evaluate fatalities. Bats appear to investigate turbines, perhaps for a number of reasons—acoustic and/or visual response to blade movement, sound attraction, and possible investigation of turbines as roosts, seem plausible given the findings and current state of knowledge. As such, further investigations are needed to determine causes of behavioral response to turbines and how to best mitigate or eliminate factors that put animals at risk of collision. Additional priority research, recommended by Arnett (2005), Arnett et al. (2008), and Kunz et al. (2007a) includes: 1) conducting extensive post-construction fatality searches for a "full season" of bat movement and activity (e.g., April through November in northern latitudes) at facilities encompassing a diversity of surrounding habitat characteristics to fully elucidate temporal patterns of fatality; 2) further investigating relationships between passage of storm fronts, weather conditions (e.g., wind speed, temperature), turbine blade movement, and bat fatality to determine predictability of periods of highest fatality; 3) investigating approaches for developing possible deterrents; testing any such deterrents should be performed under controlled conditions first, and then under a variety of environmental and turbine conditions at multiple sites; and 4) comparing different methods and tools (radar, thermal imaging, and acoustic detectors) simultaneously to better understand bat activity, migration, proportions of bats active in the area of risk, and bat interactions with turbines. It is also important to develop and verify models that allow prediction of impacts to individuals and populations of both birds and bats.

Habitat Loss, Fragmentation, and Disturbance

Two critical questions concerning habitat-related impacts remain unanswered and center on 1) the extent to which strings of wind turbines effectively fragment grassland habitat, and 2) how inferences about avoidance of trees and tall anthropogenic structures by birds transfer to avoidance of wind turbines. There is a need to determine relationships of small scale (e.g., habitat disturbance) versus large-scale habitat impacts (e.g., habitat fragmentation needs investigation) on wildlife. It is important to quantify and predict not only changes in habitat structure, but also displacement impacts, particularly on forest-dwelling and shrub-steppe/grassland birds (e.g. prairie grouse). Furthermore, development of roads for construction and maintenance may have important consequences; this issue is especially a concern in the West, which does not have as extensive networks of roads as in the Midwest. Future development of transmission lines to facilitate wind generation will undoubtedly have broad-ranging impacts on wildlife and their habitats that should be investigated as well. Likewise, potential mitigation of habitat disturbance from wind energy development, particularly in grassland habitats, through restoration of other nearby areas, should be investigated.

Habitat and Prey Density Management

Habitat modification to reduce prey densities has been discussed as a possible avian risk-reduction technique. Directly reducing prey (e.g., rodents) populations within the vicinity of wind turbines might reduce high-risk foraging activities by raptors. Suggested methods include county-sponsored abatement programs, reduced grazing intensities, and re-vegetation with higher-stature plants that pocket gophers and ground squirrels tend to avoid. The effects of widespread vegetation and/or rodent control programs would have to consider the effects on the overall demographics of the affected population as well as effects on other wildlife, such as protected species and special-status species like the San Joaquin kit fox *(Vulpes macrotis mutica)*, burrowing owl, and badger *(Taxidea taxus)*. There also may be impacts on other non-target rodent species such as kangaroo rats *(Dipodomys spp.)* and pocket mice *(Perognathus spp.)*, which have special status in some states. Research is needed to evaluate reductions in fatality relative to these management techniques.

Curtailment Experiments

Decreasing operation time of problem turbines or entire facilities has been suggested as a risk-reduction measure and recently was mandated at APWRA. Studies have reported that a large proportion of bat fatalities occur on nights with low winds and relatively low levels of power production (Feidler 2004, Arnett 2005, Brinkman 2006). Should this pattern prove to be consistent, curtailing operations during predictable nights or periods of high bat kills could reduce fatalities considerably, potentially with modest reduction in power production and associated economic impact on project operations. Thus, critical shutdown times could be predictable and implemented seasonally (e.g., during migration periods) or based on inclement weather or nighttime periods when visibility is reduced. Rigorous experimentation of moving and non-moving turbines at multiple sites to evaluate the effect on bird and bat fatality and the associated economic costs are needed. While the results from studies at APWRA, and studies just begun at Tehuantepec, Mexico, are not yet available, these datasets should provide important new information about the effects of seasonal shutdowns and turbine "feathering" (i.e., changing blade pitch to make turbines inoperative). Related research is ongoing in Europe and Canada and is anticipated in the United States beginning in 2008.

Alerting and Deterring Mechanisms

There currently is no effective alerting or deterring mechanism that has been proven to effectively reduce fatality of birds or bats. Laboratory tests suggest that some blade painting schemes may increase a bird's ability to see turbine blades (Hodos 2003), but these painting schemes have not been field-tested. Young et al. (2002) field tested the effect of painting turbines and blades with a UV gel coat, theoretically to increase a bird's ability to see the structures. However, field tests showed no difference in fatalities between treatment and control turbines. Although no research has been conducted on auditory deterrents to birds approaching wind turbines, audible devices to scare or warn birds have been used at airports, television towers, utility poles, and oil spills, yet most studies of auditory warning devices have found that birds become habituated to these devices. Birds do not hear as well as humans (Dooling 2002) and minor modifications to the acoustic signature of a turbine blade could make blades more audible to birds, while at the same time making no measurable contribution to overall noise level. Some research has been suggested on the use of infrasound, which appears to deter homing pigeons (*Columba livia*; Hagstrum 2000), but no studies have yet been conducted on this potential tool. At present there is no research under way that tests the effects of auditory deterrents on birds and, because of the low likelihood of developing a successful application, none is planned for the foreseeable future.

Development and testing of ultrasonic sound emission as a possible deterrent to bats has been undertaken in the United States (E. B. Arnett, Bat Conservation International, unpublished data); more research is needed to quantify the effectiveness of such devices at an operating facility that will include measures of fatality reduction as well as behavioral responses of bats. If such deterrents can be built and prove effective, long-term monitoring would be required at multiple sites to elucidate and justify effectiveness and determine whether bats habituate over time. Furthermore, a deterrent for bats will probably need to nullify or counteract the hypothetical attraction of some bats to wind turbines. Simply making turbines more easily perceived by bats may have no effect or could increase the hypothesized attraction. Although devices or procedures to repel bats from wind turbines may be discovered by trial and error, it is almost certain that an effective deterrent will emerge only after further basic research in the field permits us to understand the mechanism of attraction of bats to turbines (Larkin 2006).

Offshore

The priority research objective is to quantify seasonal occurrence, abundance, use, and location of birds along the Lower Gulf and Atlantic coasts. Specifically, research should focus on three major areas. First, the location, magnitude, and timing of movements of bats and birds during spring and fall migration need to be determined. It appears that a substantial number of passerines and other non-raptorial birds move along the LGC during migration, likely staying close to the coastline and along the near-shore area. Such behavior could increase risk for these species relative to direct flights out over the Gulf.

Second, identification of locations where species of concern and threatened or endangered species (bats and birds) occur during breeding and nonbreeding periods is warranted. Finally, a method for estimating fatalities at existing and planned wind facilities offshore will be required to understand impacts and develop mitigation strategies; retrieving dead birds and bats at sea will be a considerable challenge.

Cumulative Effects

We need to know not only how likely impacts are to occur, but also what the consequences will be cumulatively over time. Given the projected development of wind energy, biologically significant cumulative impacts are likely for some species. A meta-analysis, for example, conducted by Stewart et al. (2004) of bird mortality studies performed worldwide, suggests that impacts of wind facilities on bird abundance may become more pronounced over time, indicating that short-term abundance studies do not provide robust indicators of the potentially deleterious impacts of wind facilities on bird abundance. Broader assessments of the cumulative impacts for both birds and bats clearly are warranted. We also must consider the context of wildlife mortality at wind facilities in relation to other natural and anthropocentric sources of mortality, and determine if mortality from wind development is additive or compensatory.

RECOMMENDATIONS

This review identified several areas in need of immediate improvement to establish a scientific basis for decision-making, provide more rigorous and consistent requirements during permitting of wind facilities, and develop effective mitigation strategies to reduce or eliminate impacts on wildlife and their habitats from wind energy development. The following recommendations should help managers and decision-makers meet the challenges of developing wind energy responsibly.

1. Improve state agency involvement and consistency for requirements and regulation. Coordination among states and their agencies responsible for wildlife and energy development will be critical to ensure consistency in permitting requirements, research efforts, and acceptable mitigation, especially for species of migratory wildlife. Focused leadership among the states, for example, by the Western Governor's Association, would be one approach to gain acceptance of principles and guidelines for wind energy development. The Association of Fish and Wildlife Agencies could provide a useful facilitative role and has initiated dialogue with state, federal, and industry stakeholders to help reach these goals.

2. Renewable Portfolio Standards. A Renewable Portfolio Standard (RPS) is a state-level policy mandating a state to generate a percentage of its electricity from renewable sources, including wind energy. The standards usually focus on benefits of renewable energy, and currently no RPS considers the potential impacts of renewable energy's development on fish and wildlife and their habitats. Revising existing standards to account for wildlife impacts and the inclusion of this language and mitigation measures in new standards could lead to a more balanced and accurate presentation in the RPS.

3. Develop federal and state guidelines. State permitting processes vary widely in regard to environmental requirements, thus potentially hindering consistent development of objectives and implementation of methodologies. Developing consistent guidelines for siting, monitoring, and mitigation strategies among states and federal agencies would assist developers with compliance with relevant laws and regulations and establish standards for conducting site-specific, scientifically sound and consistent pre- and post-construction evaluations, using comparable methods as much as is feasible. Such consistency would greatly assist regulatory agencies during decision-making in regard to statutory trust responsibilities. Inclusion of guidelines in the permitting process would further strengthen agency participation and implementation of guidelines.

4. Avoid siting wind facilities in high-risk areas. A primary goal of wind energy development should be to avoid high-risk sites that are determined based on the best science available. Criteria and standards for high-risk sites need to be established for different groups of species and any designated "critical habitats" on a state-by-state or regional basis, and developers of wind energy should be required to avoid impacts to these areas. Examples may include locations important to threatened or endangered species or in large, contiguous areas of unfragmented native habitat. Siting wind facilities in areas where habitat is of poor quality and/or already fragmented, for example (see sidebar on Washington State guidelines), will likely result in fewer habitat-related impacts, although these sites should be monitored to determine collision impacts.

5. Reduce fragmentation and habitat effects. Developers should attempt to reduce habitat impacts by using existing roads when possible, limiting construction of new roads, and restoring disturbed areas to minimize impact from a facility's footprints. While clearing and perhaps maintaining low vegetation density will be important for post-construction surveys, habitat rehabilitation should be planned for disturbed areas after monitoring has been completed. On- and off-site habitat mitigation may be necessary to reduce habitat-related impacts.

6. Conduct priority research. Immediate research is needed to develop a solid scientific basis for decision-making when siting wind facilities, evaluating their impacts on wildlife and habitats, and testing efficacy of mitigation measures. More extensive pre- and post-construction surveys are needed to further elucidate patterns and test hypotheses regarding possible solutions. Monitoring and research should be designed and conducted to ensure unbiased data collection that meets peer review and legal standards (Kunz et al. 2007a). Research partnerships (e.g., Arnett and Haufler 2003, Bats and Wind Energy Cooperative [www.batcon.org], Grassland and Shrub Steppe Species Cooperative [www.nwcc.org]) among diverse players will be helpful for generating common goals and objectives and adequate funding to conduct studies.

7. Evaluate pre-construction assessments and predicted impacts. Prior to construction, industry, federal and state agencies, and others should conduct studies to determine what, if any, environmental risk would be posed by a planned wind facility. Resulting assessments are used in the permitting process and elsewhere. Rarely, however, is the quality of those assessments evaluated. Linking pre-construction assessments to post-construction monitoring is fundamental to assessing risk of a facility. Such comparisons are needed and would not only inform the pre-construction assessment process, but also provide valuable information about the environmental risks of wind facilities.

8. Conduct more consistent, longer-term studies. Most “research” conducted in association with wind development is short-term, and there appears to be little follow-up to determine if predictions from research are accurate. Long-term studies clearly are needed to address many questions on impacts of wind energy development on wildlife. Use of standardized protocols to address specific questions would improve comparability of studies and credibility of efforts. Consistency across data collection efforts, post-construction evaluations, and access to resulting data will be critical for conducting meta-analyses so that consistent effects, even if they are small, could be detected.

9. Develop and evaluate habitat-related mitigation strategies. All too often, mitigation measures have been generally required without adequate evaluation. Strategies for mitigating habitat impacts associated with wind facilities should be developed and evaluated. Effective mitigation measures should then be employed.

10. Employ principles of adaptive management. Operations and mitigation strategies should be adjusted as new information becomes available, following the principles of adaptive management (Walters 1986, Walters and Holling 1990). For example, future permitting requirements and guidelines should clearly define monitoring standards, mitigation measures (e.g., curtailment), and how data will be used to trigger adjustments to operations to mitigate impacts on wildlife. Strategies should be adjusted as new information becomes available.

11. Conduct regional assessments and forecasting of cumulative land-use and impacts from energy development. Given projected increases in multiple sources of energy development, including biomass, wind, and oil and gas development, future conflicts surrounding land-use, mitigation, and conservation strategies should be anticipated. Habitat mitigation options, for example, when developing wind in open prairie, may be compromised by development of other energy sources. Regional assessments of existing and multiple forecasts of possible land uses are needed, and planning regional conservation strategies among industries, agencies, and private landowners could reduce conflicts and increase options for mitigation and conservation.

12. Improve public education, information exchange, and participation. There is an immediate need to better educate the public and decision-makers regarding the full range of trade-offs and benefits regarding all forms of energy, including wind energy development. Impacts on wildlife and their habitat must be integrated into the political dialogue so that all tradeoffs can be considered during decision-making. Maintaining relationships with private landowners and communicating the importance of conservation efforts and their benefits will be critical toward developing wind energy responsibly. ■

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Table 1. Avian fatality rates from new generation wind facilities where standardized fatality monitoring was conducted.

	Project Size		Turbine Characteristics			Raptor Fatality Rates		All Bird Fatality Rates		Source
	#	#	RD	RSA		#/	#/	#/	#/	
Wind Project	turbines	MW	(m)	m^2	MW	turbine	MW	turbine	MW	
Pacific Northwest										
Stateline, OR/WA	454	300	47	1735	0.66	0.06	0.09	1.93	2.92	Erickson et al. 2004
Vansycle, OR	38	25	47	1735	0.66	0.00	0.00	0.63	0.95	Erickson et al 2000
Combine Hills, OR	41	41	61	2961	1.00	0.00	0.00	2.56	2.56	Young et al. 2005
Klondike, OR	16	24	65	3318	1.50	0.00	0.00	1.42	0.95	Johnson 2003
Nine Canyon, WA	37	48	62	3019	1.30	0.07	0.05	3.59	2.76	Erickson et al. 2003
Overall	586	438	56	2554	1.02	0.03	0.03	2.03	2.03	
Weighted averages	586	438	49	1945	0.808	0.05	0.07	1.98	2.65	
Rocky Mountain										
Foote Creek Rim, WY Phase I	72	43	42	1385	0.60	0.03	0.05	1.50	2.50	Young et al. 2001
Foote Creek Rim, WY Phase II	33	25	44	1521	0.75	0.04	0.06	1.49	1.99	Young et al. 2002
Totals or simple averages	105	68	43	1453	0.675	0.04	0.05	1.50	2.24	
Totals or weighted averages	105	68	43	1428	0.655	0.03	0.05	1.50	2.31	
Upper Midwest										
Wisconsin	31	20	47	1735	0.66	0.00	0.00	1.30	1.97	Howe et al. 2002
Buffalo Ridge Phase I	73	22	33	855	0.30	0.01	0.04	0.98	3.27	Johnson et al. 2002
Buffalo Ridge Phase II	143	107	48	1810	0.75	0.00	0.00	2.27	3.03	Johnson et al. 2002
Buffalo Ridge, MN Phase III	139	104	48	1810	0.75	0.00	0.00	4.45	5.93	Johnson et al. 2002
Top of Iowa	89	80	52	2124	0.90	0.01	0.01	1.29	1.44	Koford et al. 2004
Totals or simple averages	475	333.96	46	1667	0.67	0.00	0.01	2.06	3.13	
Totals or weighted averages	475	333.96	46	1717	0.53	0.00	0.00	2.22	3.50	
East										
Buffalo Mountain, TN	3	2	47	1735	0.66	0.00	0.00	7.70	11.67	Nicholson 2003
Mountaineer, WV	44	66	72	4072	1.50	0.03	0.02	4.04	2.69	Kerns and Kerlinger 2004
Totals or simple averages	47	68	60	2903	1.08	0.02	0.01	5.87	7.18	
Overall (weighted average)	47	68	70	3922	1.45	0.03	0.02	4.27	2.96	

Table 2. Estimates of bat fatalities at wind facilities in North America (modified from Arnett et al. 2007).

Study Area Location	Estimated Fatality/Turbine	Estimated Fatality/MW	Source
Canada			
Castle River, AB	0.5	0.8	Brown and Hamilton 2002
McBride Lake, AB	0.5	0.7	Brown and Hamilton 2006a
Summerview, AB	18.5	10.6	Brown and Hamilton 2006b
Eastern U.S.			
Buffalo Mt, TN (Phase 1) [a]	20.8	31.5	Nicholson 2003, Fiedler 2004
Buffalo Mt, TN (Phase 2, 0.66 MW) [a]	35.2	53.3	Fiedler et al. 2007
Buffalo Mt, TN (Phase 2, 1.8 MW) [b]	69.6	38.7	Fiedler et al. 2007
Maple Ridge, NY	24.5	14.9	Jain et al. 2007
Meyersdale, PA	23	15.3	Arnett 2005
Mountaineer, WV (2003)	48	32	Kerns and Kerlinger 2004
Mountaineer, WV (2004)	38	25.3	Arnett 2005
Rocky Mountains U.S.			
Foote Ck. Rim, WY	1.3	2.0	Young et al. 2003
Pacific Northwest U.S.			
Highwinds, CA	3.4	1.9	Kerlinger et al. 2006
Klondike, OR	1.2	0.8	Johnson et al. 2003b
Stateline, OR/WA	1.1	1.7	Erickson et al. 2003b, 2004
Vansycle, OR	0.7	1.1	Erickson et al. 2001
Nine Canyon, WA	3.2	2.5	Erickson et al. 2003a
Midwestern U.S.			
Buffalo Ridge, MN Phase 1) [c]	0.1	0.3	Johnson et al. 2003a
Buffalo Ridge, MN (Phase 2) [d]	2.0	2.7	Johnson et al. 2003a, 2004
Buffalo Ridge, MN (Phase 3) [e]	2.1	2.7	Johnson et al. 2004
Lincoln, WI	4.3	6.5	Howe et al. 2002
Top of Iowa	7.8	8.7	Jain 2005
South-central U.S.			
Woodward, OK [f]	1.2	0.8	Piorkowski 2006

[a] Estimated bats killed by 3 Vestas V47 0.66 megawatt turbines.
[b] Estimated bats killed by 15 Vestas V80, 1.8 megawatt turbines.
[c] Estimated bats killed by 73 Kenetech 33 0.33 megawatt turbines based on 4 years of data.
[d] Estimated bats killed by 143 Zond 0.75 megawatt turbines based on 4 years of data.
[e] Estimated bats killed by 138 Zond 0.75 megawatt turbines based on 3 years of data.
[f] Estimated average over eight surveys in two years.

Table 3. Densities of male grassland birds (all species combined) in Conservation Reserve Program fields along transects at various distances from strings of wind turbines, and at a control site, in southwestern Minnesota (from Leddy et al. 1999).

Distance from turbine string (m)	Mean density of males (per 100 ha)
0 m	58.2
40 m	66.0
80 m	128.0
180 m	261.0
Control	312.5