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A Roadmap for PIER Research on Avian Collisions with Wind Turbines in California

COMMISSION STAFF REPORT

December 2002
P500-02-070F

Gray Davis, *Governor*

CALIFORNIA ENERGY COMMISSION

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Acknowledgements

The author and PIER would like to thank the following individuals for their invaluable help in preparing this document:

- Richard Anderson/California Energy Commission.
- Ed Colson/Pacific Gas and Electric Company.
- Wally Erickson/Western Ecosystems Technology Inc.
- Jim Estep/ Jones & Stokes.
- Grainger Hunt/Predatory Bird Research Group
- William Hodos/University of Maryland.
- Brian Keeley/Bat Conservation International.
- Sue Orloff/Ibis Environmental, Inc.
- Linda Spiegel/California Energy Commission.
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Executive Summary

The purpose of this roadmap is to summarize the current status of avian-wind turbine collision research, evaluate the current knowledge of risk reduction, and provide recommendations for future research. Potential researchers can use this roadmap to help determine research priorities, and evaluators can use it to help determine whether a particular proposal meets current research goals.

Although wind power is considered to be one of the most environmentally friendly energy sources, it has been shown to cause bird and bat fatalities. In some cases, wind turbines may pose a threat to local avian populations and to certain special-status species that have been given legal protection. A recent study reported that 1,000 or more bird fatalities may occur at Altamont every year, with about 50% of these being raptors, and nearly all protected by the Migratory Bird Treaty Act, the Bald Eagle and Golden Eagle Protection Act, and/or the Endangered Species Act. Raptors are also protected under California Fish and Game Code 3503.5, which makes it illegal to "take", possess, or destroy any raptor. The U.S. Fish and Wildlife Service considers any injury or mortality of any raptor from a collision with a wind turbine, or ancillary facilities to be a "take" and, therefore, a violation of the law. Violations can result in fines from $100,000 to $500,000.

Public perception, state and federal protection laws, and potential fines and lawsuits have resulted in delays, modifications, and stoppages of new wind energy projects in California and other states. For example, Alameda County will not approve additional permit applications to increase current electrical production (~580 MW) at Altamont Pass Wind Resource Area until significant progress toward solving the bird fatality issue is demonstrated. It is estimated that the current capacity, which is well below the existing permitted capacity of 800MW could be at least doubled.

Avian fatality studies have been conducted at several wind resource areas. In many cases, it has been difficult to compare results from one study or one site to another, because survey methods and site conditions vary. In addition, few studies have been published and subjected to peer review. Despite these problems, researchers have found that the majority of wind turbine-caused bird fatalities appear to occur in California, primarily at the Altamont Pass Wind Resource Area (WRA). In particular, some raptor species appear to be at greater risk than other, more abundant, species.

There are likely a number of factors responsible for a higher number of fatalities in California. California led the rest of the United States in wind energy development in the 1980s, before there was widespread recognition of potential bird fatality risks. The Altamont Pass WRA was built in an area with a high density of raptors and a diverse topographic environment. By accident or design, newer wind generation facilities have not been placed in areas with high-density raptor populations or the risk-related topographic diversity. In addition, newer facilities generally install a smaller number of more widely spaced wind turbines. Newer WRAs use newer-generation wind turbines that are larger, more efficient and posses other characteristics that may reduce risk as well, although these features remain untested in high-risk areas such as the Altamont Pass WRA.

Researchers have performed very few studies to determine the overall impacts of wind turbines on the population viability of an individual species. Concern has focused on the impacts of wind turbines on raptor species (particularly the golden eagle) at the Altamont Pass WRA. Although a golden eagle population model based on a seven-year radio telemetry study indicated that the population appeared stable, researchers have cautioned that continued land conversion around the WRA and wind-turbine related fatalities could affect future populations.

The causes of bird fatalities may be attributable to a number of different factors, including bird behavior, high prey abundance, turbine design, spatial arrangement of turbines, and topography. It is likely that a combination of these factors is involved. Behavioral characteristics of certain raptors, such as flying at low altitudes and focused searching and stooping for prey, may make them more susceptible to collisions. At the Altamont Pass WRA, golden eagles may be particularly susceptible, because of their particular flight behavior and because of the abundance of ground squirrels, in proximity to wind turbines. In addition, raptors and other birds may not see the blade tips of rapidly rotating wind turbine rotors because motion smear makes them appear transparent.

Several different wind turbine types can be found in California’s WRAs. It is possible that several design features, such as available perch sites, number of blades, maximum and minimum blade heights, blade velocity, rotor-swept area, and fixed versus variable turbine speed could influence the relative risk of bird collision. Researchers have found it difficult to determine the overall risk of these individual variables, as it is likely that they not only interact with one another, but also with other variables such as site characteristics (e.g. topography) and spatial arrangements.

Because of their higher efficiency and reduced average rotational and tip speeds, the newer, larger machines being proposed to replace existing turbines in California exhibit some potential to reduce fatalities. It will be necessary to rigorously monitor these turbines at the Altamont Pass Wind Resource Area to evaluate their risk in comparison to existing turbine types.

The association between spatial distribution of wind turbines and fatality rates has been evaluated at a variety of sites. However, variation in site characteristics and turbine arrangement and design at WRAs has made it difficult to derive conclusive patterns. Although some research indicates that end-of-row turbines are correlated with higher raptor fatalities because of their proximity to canyons and seep terrain, other studies have indicated that irregular spacing patterns and differences in turbine densities might be correlated with higher fatality risk.

Placing turbines in association with specific topographic features within WRAs may have an effect on the frequency of bird collisions. Turbines associated with canyons, mid-row depressions, and ridge ends have been correlated with higher fatalities. Models that identify risk in association with topographic features as well as spatial configurations and turbine design characteristics will be useful in determining turbine selection and their suitable placement at current high-risk WRAs. A model currently being developed at the Altamont Pass WRA and funded by the California Energy Commission's Public Interest Energy Research–Environmental Area (PIEREA) could be used to identify, modify or remove existing high-risk turbines, and could also be applied during future projects to help site the location of newer replacement turbines.

Avoidance of high-risk areas where species susceptible to collision risk occur in relative abundance is the best solution for future wind energy developments. The National Wind Coordinating Committee (NWCC) has produced a handbook to address wind generation siting and permitting issues, and it recommends measures to avoid, potential high-risk areas, and the use of standardized study techniques. The NWCC also developed a comprehensive guide to standardized methods and metrics for determining potential risk and impacts to birds at existing and future wind farm sites.

At the Altamont Pass WRA, early research also raised concern about bird fatalities caused by electrocution and wire collisions. Retrofitting distribution lines with risk-reduction devices occurred throughout much of the Altamont Pass WRA and appears to have reduced bird electrocutions significantly. It appears that there is technology available to avoid most electrocution and wire collision risk at wind facilities and risk appears to have been reduced considerably at existing facilities. At new facilities, with the use of underground or raptor-safe transmission lines, installation of perch guards and the elimination of guyed wind turbines and meteorological towers, virtually all avian wire collision and electrocution fatality risk can be avoided.

Few bat fatalities have been reported at California WRAs, whereas a few facilities outside of California have reported a larger number. Some bat biologists have suggested the possibility that these fatalities could have a significant impact on bat populations. There are several special status bat species in California. The actual number of fatalities that now occur is likely underestimated, because bats are much more difficult to detect than most bird species during conventional bird fatality searches. Researchers cannot use the same survey methods or equipment to perform bat use surveys at wind facilities that they use to survey birds. Bat experts need to be consulted to identify potential bat threats at specific WRAs and to develop an appropriate carcass recovery methodology.

Future research should focus on the refinement of pre-project risk assessment and risk reduction at existing sites. The information gained to date, in conjunction with pre-construction assessments of bird use, has made it possible for some wind turbine developments to reduce some avian fatality risk significantly. However, more effective and economical risk-avoidance techniques need to be developed for proposed wind facilities. In addition, fatalities at the Altamont Pass WRA continue to be high, and new developments proposed at sites with known high bird use (such as Solano County) warrant further research to develop techniques to further reduce risk. Future research should concentrate on completing the analyses needed to understand the factors that contribute to risk, developing methods to reduce those risks, and monitoring to determine the effectiveness of those measures.

In the short-term (1–3 years) this roadmap recommends that the following objectives be addressed:

Objective	**Projected Cost ($000)**
• Update Wind Turbine Effects Bibliography	30
• Develop a Risk Assessment Model of the Altamont Wind Resource Area	40
• Continue Studies to Assess Turbine/Site Characteristics Associated with Fatalities	200
• Conduct Wind Resource Area Repowering Studies	450*
• Identify Risks of Potential Wind Resource Areas	100
• Conduct a Study of Habitat Manipulation Feasibility	50
• Conduct Video Monitoring at High-Risk Wind Turbines	150
Total	**1020**

Note: An asterisk (*) indicates a high probability that the work will be leveraged with other ongoing efforts. The figure given is the California Energy Commission's projected expenditure.

The Roadmap for PIER Research on Avian Interactions with Wind Turbines in California also identifies mid-term (3–10 year) and long-term (10–20 year) goals, some of which build on the short-term work listed above.

Roadmap Organization

This roadmap summarizes the current status of avian-wind turbine collision research, evaluates the current knowledge of risk reduction, and provides recommendations for future research. Potential researchers can use it to help determine research priorities, and evaluators can use it to help determine whether a particular proposal meets current research goals. The sections build upon each other to provide a framework and justification for the proposed research and development.

Section 1 states the issue to be addressed. *Section 2: Public Interest Vision* provides an overview of research needs in this area and how PIER plans to address those needs. *Section 3: Background* establishes the context of PIER's work addressing avian interactions with wind turbines. *Section 4: Current Research and Research Needs* surveys current projects and identifies specific research needs that are not already being addressed by those projects. *Section 5: Goals* outlines proposed PIEREA activities that will meet those needs. *Section 6: Leveraging R&D Investments* identifies methods and opportunities to help ensure that the investment of research funds will achieve the greatest public benefits. *Section 7: Areas Not Addressed by this Roadmap* identifies areas related research pertinent to avian interactions with wind turbines that the proposed activities do not address. *Appendix A: Current Status of Programs* offers an overview of work being done to address avian/wind turbine issues.

Glossary

End-of-row turbine – Turbines that are located on either end of a turbine string. Turbine strings are generally from 3–10 turbines long in the Altamont Pass Wind Resource Area.

Guy wire – Wire or cable used to secure and stabilize wind turbines, meteorological towers, and other vertical objects in wind resource areas. Most wind turbine towers are self-supporting and do not require guy wires.

Horizontal axis – The axis of rotation of the power shaft relative to the ground is parallel to the ground. This is by far the most common axis orientation in existing wind resource areas.

Horizontal lattice turbine – A wind turbine tower that is composed of a steel lattice structure. Many steel lattice support structures run parallel to the ground, providing considerable perching space to birds.

Nacelle – The housing that protects the generator and gear box in horizontal axis turbines.

Pitch – Rotors are characterized as either fixed or variable-pitched. Fixed-pitch machines have blades positioned at a stationary angle to the wind. Variable-pitch machines have a mechanism that adjusts the angle of the blades relative to the wind, to maximize and control performance. A variable-pitch blade allows turbines to operate over a wider range of wind speeds.

Rotational speed – The rate (in revolutions per minute) at which a turbine blade makes a complete revolution about its axis. Wind turbine rotational speeds can be fixed or variable.

Rotor center – The distance from the ground to the center of the circular area that is swept by the rotating blades.

Rotor diameter – The diameter of the circular area that is swept by the rotating tip of a wind-turbine blade. Rotor diameter is equal to two times the blade length.

Rotor orientation (Yaw) – The rotation in the horizontal plane of a horizontal axis turbine by which the rotor is oriented into the wind.

Rotor-swept area – The circular area that is swept by the rotating blades. Doubling the length of blades quadruples the blade-swept area. In general, capacity is proportional to blade-swept area. Annual rotor-swept area is the area that one turbine rotor will sweep in a one-year period, taking into account average annual rotational speed (rpm), average annual percent operation time, and rotor diameter.

Glossary

(Continued)

Tip speed – The speed (in miles per hour) that the tip of the blade travels when the rotor is turning. At comparable wind speeds, a horizontal axis turbine with a longer rotor experiences a slower rpm, while the tip speed remains roughly constant.

Tower type – The turbine tower supports the rotor and nacelle. Towers are constructed of metal and are commonly tubular or latticed steel. Towers that are not self-supporting require guy wires.

Turbine height – The maximum height reached by the blade tips of a wind turbine.

Turbine spacing – The distance between wind turbines in a string. Generally, the distance between turbines is proportional to the rotor diameter.

Variable/Fixed speed – Rotors may be of varied or fixed speed. Variable-speed rotors turn faster as wind velocity increases, whereas fixed-speed rotors maintain a constant speed. Some turbines have dual-speed generators that shift between two fixed speeds, depending on the wind velocity.

Vertical axis – The axis of rotation of the power shaft relative to the ground is perpendicular to the ground. Vertical axis turbines (commonly called "eggbeaters") represent relatively old technology. No new vertical axis turbines have been installed in California since 1986 (Alameda County 1998).

1. Issue Statement

Avian collisions with wind turbines have resulted in thousands of annual bird fatalities that violate State and federal laws and may delay or stop new wind power developments. There is a need to develop new methods and tools to reduce or avoid the incidence of avian collisions with wind turbines in California.

2. Public Interest Vision

A primary goal of the Public Interest Energy Research (PIER) program is "…to provide a clean, affordable, reliable, and resilient supply of electricity…" to California citizens. Wind power is a proven renewable energy technology and the fastest-growing energy source in the world—supplying electricity to more than 10 million households worldwide. Many areas of California have winds capable of powering this cost-effective, renewable technology, and wind power developers are interested in repowering existing wind facilities and developing new ones in California, to take advantage of these resources.

Wind turbines provide numerous benefits. They do not rely on fossil fuels, and therefore could help the State achieve energy independence. They emit no air pollutants, so they help reduce the health and environmental problems associated with fossil-fuel power plants. They are competitive with the cost of producing electricity from fossil-fuel power plants. In fact, the cost of producing electricity with wind turbines has decreased nearly four-fold since 1980, and the Energy Commission estimates that newer technologies can generate electricity for 3.5 cents per kWh. Moreover, they can be installed individually or in groups (sometimes called "wind farms") to meet the small or large electricity needs of a particular region. All in all, wind turbines could play a key role in helping California meet its goals of supplying ample, clean energy to a growing population.

In 1995, California produced 30 percent of the world's wind-generated electricity (2.9 billion kilowatt hours), yet wind development slowed considerably in the 1990s. One reason for this decline was that researchers began to document bird fatalities from collisions with wind turbines (particularly at the Altamont Pass Wind Resource Area, or WRA), which raised enough concern to delay or stop development of a considerable amount of wind turbine capacity in the state.

Currently, ninety-five percent of the state's wind generating capacity and output is located in the Altamont Pass, Tehachapi, and San Gorgonio WRAs. A recent study reported that 1,000 or more bird fatalities may occur at Altamont every year, with about 50% of these being raptors, and nearly all protected by the Migratory Bird Treaty Act, the Bald Eagle and Golden Eagle Protection Act, and/or the Endangered Species Act. Raptors are also protected under California Fish and Game Code 3503.5, which makes it illegal to "take", possess, or destroy any raptor. The U.S. Fish and Wildlife Service considers any injury or mortality of any raptor from a collision with a wind turbine, or ancillary facilities to be a "take" and, therefore, a violation of the law. Violations can result in fines from $100,000 to $500,000.

Studies conducted at the Tehachapi Pass and San Gorgonio WRAs have documented less significant numbers of bird fatalities, indicating that conditions at Altamont Pass WRA may be an anomaly. However, new developments are being proposed at sites with known high bird use and avian mortality at WRAs has raised concerns by state and federal agencies, conservation groups, and industry. To date, measures to mitigate existing fatalities have not been enacted. As a result, the wind industry is faced with permitting barriers and possible fines and lawsuits.

To ensure that California is able to benefit from its wind resources while minimizing bird and bat collisions with wind turbines, research and development is needed in a number of areas. First, there is a need to revise the Energy Commission report *Effects of Wind Energy Development: An Annotated Bibliography,* to compile the information that has been collected on this topic since the bibliography was published in 1996. For this revision, it is hoped that wind developers and utility companies will contribute some of their independent research data that has, as yet, been unavailable. Second, there is a need to develop a risk assessment model - and use it in areas such as the Altamont Pass WRA to assess current installations and evaluate future wind turbine developments. Third, researchers must continue and expand studies now under way to assess which turbine/site characteristics have been associated with bird fatalities. Fourth, researchers should conduct an Altamont Pass WRA repowering study that will evaluate the effects of planned repowering on birds and field-test the efficacy of repowering with larger capacity turbines. Fifth, researchers should identify the risks of potential wind turbine developments by analyzing U.S. wind turbine studies that have employed the standardized National Wind Coordinating Committee methodology for assessing risk variables. Sixth, research must determine the feasibility of manipulating habitats to reduce prey abundance in and around wind turbine facilities. Finally, researchers need to conduct video monitoring at high-risk wind turbines to identify causes of bird fatalities.

Californians will benefit directly from this work through reduced avian fatalities and the ability of industry to comply with State and federal laws protecting most birds. However, the State will also benefit from increased generating capacity, improved electricity system reliability, and decreased air emissions. The conditional use permit issued by Alameda County states that there can be no net increase in the current electrical production from the Altamont WRA until the bird fatality issue is resolved and it can be demonstrated that fewer fatalities are occurring there. It is estimated that current capacity (583 MW), which is well below the existing permitted capacity (approximately 800 MW) at Altamont, could be doubled, at a minimum. In addition, reducing costs associated with repowering and environmental reviews will reduce the cost of producing California's electricity.

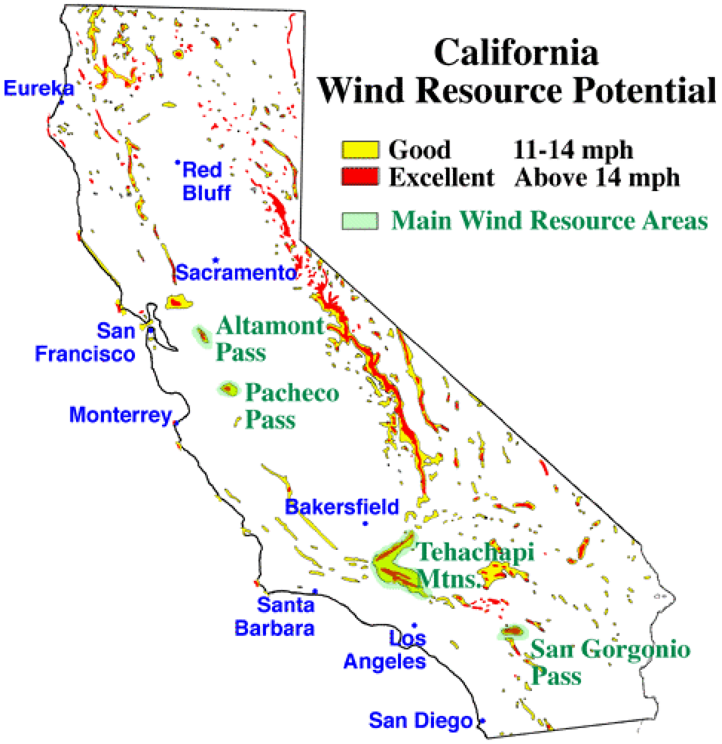
The successful completion of the activities suggested in the Goals section (Section 5) will help wind power plant developers, researchers, and state and federal regulators work together to reduce avian fatalities from collisions with wind turbines, while increasing the use of wind power in the state.

3. Background

3.1 Wind Power in California

Wind power has been used commercially to produce energy since the early 1980s, when the world's first large-scale wind development, or wind resource area (WRA), was built in California. Wind power has become one of the most promising renewable energy technologies for electricity generation in the United States, and there are currently 22 states with Wind Resource Areas (WRAs), with many more in the planning process (Erickson et al. 2001). As shown in Figure 1, California has rich wind resource potential throughout the State. Ninety-five percent of the state's wind generating capacity and output is located in three primary regions: Altamont Pass, Tehachapi, and San Gorgonio. Wind power is considered one of the most environmentally friendly energy sources on a global scale because it produces no emissions, is relatively inexpensive, is compatible with many other land uses, and has potential for reducing U.S. dependence on foreign fuel sources.

Figure 1. California Wind Resource Potential.



Source: A. Miller and R. Simon, *Wind Power in California*, San Jose State University, prepared for the California Energy Commission, May 1978.

Wind power developments however, have been shown to cause avian mortalities. Erickson et al. (2001) recently projected that 15,000 turbines operating in the United States by the end of 2001 would produce a range of 10,000 to 40,000 bird fatalities a year, with 81 percent of these occurring in California. In some cases, there may be threats to local populations, and most birds including raptors and migratory species are given legal protection. In light of the cumulative effects of all human-caused avian mortalities, any efforts to reduce mortalities become important.

California led the rest of the United States in wind energy development in the late 1980s and early 1990s, producing over 90 percent of the country's wind energy output. By 1995, California produced 30 percent of the world's wind-generated electricity (2.9 billion kilowatt hours). In the early years, the potential impacts of wind developments on birds were recognized by avian biologists, but not given serious consideration until compelling data on bird fatalities was reported. In the late 1980s, avian fatalities—particularly those of raptors at the Altamont Pass WRA—became more evident. This information prompted a number of studies to determine the impacts of other California WRAs on birds (CEC 1996).

In addition to the recognition of avian fatalities, a number of other factors—including uncertainty from restructuring the electric industry, loss of federal and state economic incentives, and expired utility contracts—contributed to slowed wind development in the late 1990s. Since that time, public perception, state and federal protection laws, and potential fines and lawsuits have resulted in delays, modifications, and stoppages of new wind energy projects in California and other states (Erickson et al. 2001).

Current conditions in the state's electricity outlook is creating more favorable markets for wind energy and older, less-efficient wind turbines are being replaced by much larger turbines with increased generating capacity. These newer wind facilities have fewer raptor fatalities than that documented at the Altamont Pass WRA. Much of this improvement has not been by design, but simply because these wind energy facilities were sited in areas that typically have lower raptor densities and less topographic diversity than the Altamont Pass WRA. Some avoidance of either high risk wind facility sites or high risk locations within wind facilities has been due to pre-construction site evaluations (Sinclair pers. comm., Strickland pers. comm.) and a standardized approach to evaluating wind power projects developed by the National Wind Coordinating Committee (NWCC; Anderson et al. 1999). In addition, reduced concentrations of turbines in newer WRAs, and possibly newer turbine designs, may have contributed to avoiding the high number of raptor fatalities that occur at the Altamont Pass WRA. However, researchers still need more information on how to reduce fatalities at existing facilities. In addition, it is not known if the newer generation turbine designs slated to replace many of the old turbines will reduce avian fatalities. Consequently, research still needs to focus on other risk-reducing measures that involve changes in turbine design and microsite selection.

Until recently, little research has been conducted to determine the impacts of wind farms on bats. A few bat carcasses were found during earlier bird fatality studies; however, recent surveys at some newer sites have discovered higher mortalities than reported previously. To better discern the level of collision impacts on bats, researchers have initiated studies at some of these sites.
Collision with the rotating blades of wind turbines is not the only significant impact that wind facilities may have on birds. Power lines distributed throughout WRAs have caused bird electrocutions, particularly to larger raptors already at risk from wind-turbine collisions. In addition, bird collisions with power lines, guy-wired turbines, and meteorological towers have been documented and need to be considered as potential contributors to avian risk at existing and proposed wind facilities.

Wind energy offers a relatively environmentally benign source of electricity and many more wind projects are being proposed throughout the United States and Europe. Finding solutions to the wind turbine/bird fatality issue would help assure government, wind industry, and the public that permitting wind development is being conducted in an environmentally responsible manner.

3.2 The PIER Focus

Research data is currently inadequate to properly address the issue of avian fatalities from collisions with wind turbines in California. Although the research community is slowly beginning to gather data on this issue, large data gaps still exist concerning the extent of the problem, its various causes, and effective mitigation strategies. Moreover, public research to address this issue is largely nonexistent, and much of the research that is being conducted on this topic is proprietary, and therefore, unavailable to the larger research community.

Part of the mission of PIER is to conduct and fund research in the public interest that would otherwise not occur. The issue of avian/wind-turbine interactions is one such issue. PIEREA aims to address this topic through its own targeted research and to attract collaborators that will share data and work with PIEREA to develop mitigation strategies.

PIEREA is also developing roadmaps to address avian electrocution with power lines, and avian collision with power lines. Whenever possible, PIEREA will coordinate these programs and seek outside collaborators to leverage funding and avoid overlapping research.

4. Current Research and Research Needs

The following discussions outline the status of current work and identify scientific and research gaps in three areas:

1. Avian/Wind Turbine Interactions
2. Bat/Wind-Turbine Collisions
3. Avian Electrocution and Wire Collision Impacts in Wind Resource Areas

4.1 Avian/Wind-Turbine Interactions

4.1.1 Determining Avian Fatalities

Researchers have conducted a large number of avian fatality surveys at WRAs in the United States and Europe. In most cases, several factors have made it difficult to compare results from one study or one site to another. First, survey methods vary, and very few of these studies have been peer reviewed and published in scientific journals. In particular, carcass detection and carcass removal bias have often not been measured. Second, turbine design and wind farm layouts vary considerably from site to site. Third, the wide climatic and topographical differences and range of bird species present in different locations makes it extremely difficult to draw concrete conclusions from the available literature. Fourth, it is difficult to make statistical comparisons because the relatively low number of fatalities results in inadequate sample size. In addition, there has been an emphasis on raptor fatalities, despite the knowledge that other birds have been affected—perhaps because raptors receive protection under a large suite of federal and state laws, and because they are symbolic and have greater emotional value (Anderson et al. 1996). A sampling bias towards raptors and other large birds also occurs because small birds are more difficult to detect and scavenging of small birds can be expected to be more rapid (Erickson et al. 2001). Impacts to some passerines, including neotropical migrants, may warrant more careful scrutiny, because many of them are protected under the Federal Migratory Bird Treaty Act and because some are experiencing regional population declines.

In spite of these difficulties, some general comparisons can be made about the degree of risk among WRAs. Tables 1, 1a, and 2 summarize and compare some of these results.

4.1.1.1 California Studies.

Avian collisions with wind turbines became noticeable in the 1980s, when California began to lead the nation in larger wind energy sites, and researchers began to investigate the problem's severity. A 1985 study at the San Gorgonio WRA documents 40 collisions involving 25 species of birds, including one raptor. An extrapolation of these data yielded an overall estimate of as many as 6,800 birds killed per year, most of them nocturnal passerine migrants (McCrary 1986). A 1989 Energy Commission report (Estep 1989) provided some of the first documentation that a significant number of raptor fatalities were occurring at California WRAs. This report, using four years (1984–1989) of incidental data collected from government agencies, industry, and bird rehabilitation centers, documented 72 raptor collisions with wind turbines at the Altamont Pass and Tehachapi

WRAs. These fatalities were primarily red-tailed hawks (*Buteo jamaicensis)* and golden eagles (*Aquila chrysaetos)*.

In the late 1980s, researchers began more systematic surveys of the Altamont Pass and Solano County WRAs. Howell and Didonato (1991) completed a one-year study of the Altamont Pass WRA that sampled 359 of over 3,000 turbines on the U.S. WindPower site and reported 42 bird fatalities. They did not attempt to make an annual estimate of fatalities for the entire site, but indicated that the estimated fatality rate of golden eagles on the study site (10 per year based on a four-year, non-systematic self-monitoring survey by U.S. WindPower) could have a significant impact on local populations. A two-year study of the Solano County WRA found 22 fatalities after sampling 237 of 600 wind turbines (Howell and Noone 1992). Thirteen of these birds were raptors. Orloff and Flannery (1992) conducted a two-year survey of the Altamont Pass WRA, sampling 1,169 of 7,340 turbines and determined that 100 of the 188 recovered dead birds were likely killed by collisions with wind turbines. Estimates of annual raptor fatalities extrapolated to the entire WRA, ranged from 403 in the first year to 163 in the second year with estimates of as many as 39 golden eagles killed each year. Additional studies at the Altamont Pass WRA by Orloff and Flannery (1996) and Howell (1997) yielded 20 observed fatalities (15 raptors) and 72 observed fatalities (44 raptors) respectively (see Table 1a).

A study of golden eagle populations in the vicinity of the Altamont Pass WRA from 1994 to 2000 reported that 52 of 257 eagles equipped with radio transmitters were killed by wind turbine strikes (Hunt 2002). A fatality survey conducted by Thelander and Rugge (2001) from March 1998 to December 2000 at the Altamont Pass WRA sampled 1,110 of 5,400 turbines using more systematic and intensive search efforts than in previous studies at this site. Their results, 369 confirmed bird collisions with wind turbines of which 203 (55 percent) were raptors, indicated that bird fatalities might occur at greater rate than previously reported.

When compared with the San Gorgonio and Tehachapi WRAs, it is clear that the Altamont Pass WRA supports substantially higher resident and migratory raptor populations, and experiences substantially greater raptor fatality rates caused by collision with wind turbines. Fatality studies at the San Gorgonio and Tehachapi WRAs found relatively lower fatality rates for birds (including raptors) than have been reported at the Altamont Pass WRA (Orloff 1992; Anderson pers. comm.; Table 2). A one-year study at San Gorgonio found a total of 42 bird fatalities, including 7 raptors, and a three-year study at Tehachapi Pass found a total of 147 bird fatalities, including 46 raptors (Anderson pers. comm.).

Table 1. Description of studies of avian fatalities used for species composition or fatality estimates (Outside of California).

WRA	Turbine Types	Dates of Study	# of Turbines in WRA	# of Turbines Searched	Search Interval	Total # Observed Fatalities	# of Raptor Fatalities	Reference
Buffalo Ridge, MN Phase I	Kenetech Model 33-MVS	4/94-12/95	73	50	7 days	12	0	Osborn *et al.* 2000.
Buffalo Ridge, MN Phase I	Kenetech Model 33-MVS	3/96-11/99	73	21	14 days	13	1	Johnson *et al.* 2000b.
Buffalo Ridge, MN Phase II	Zond Z-750	3/98-11/99	143	40	14 days	22	0	Johnson *et al.* 2000b.
Buffalo Ridge, MN Phase III	Zond Z-750	3/99-11/99	138	30	14 days	20	0	Johnson *et al.* 2000b.
Foote Creek Rim, WY Phase I	Mitsubishi 600 kW tubular	11/98-10/99	69	69	28 days	95	5	Johnson *et al.* 2001.
Green Mountain Searsburg, VT	Zond Z-40	6/97-10/97	11	11	Weekly/ Monthly	0	0	Kerlinger 1997.
IDWGP Algona, IA	Zond Z-50	10/99-7/00	3	3	14 days	0	0	Demastes and Trainer 2000.
Ponnequin, CO	NEG/MICO N750 kW	11/98-11/00	29	29	3 days-1.5 mo.	9	0	Kerlinger *et al.* 2000.
Somerset County, PA	Nordex 1300 kW	6/00-1/00	8	8	Weekly-Monthly	0	0	Kerlinger 2000, pers. comm.
Vansycle Ridge, OR	660 kW Vestas	1/99-12/99	38	38	28 days	12	0	Erickson *et al.* 2000b.
Wisconsin (MG&E and PSC)	Vestas 660 kW	Spring 98-12/00	31	31	Daily-Weekly	21	0	Howe 2001, pers. comm.

Source: Erickson et al. 2001.

[a] Types of fatalities included often vary by study. For example, in some studies, feather spots are included or electrocutions are included. In other studies, only fresh carcasses that are likely turbine kills are included. Sometimes incidental discoveries are included; other times they are not.

Table 1a. Description of studies of avian fatalities used for species composition or fatality estimates (California).

WRA	Turbine Types	Dates of Study	# of Turbines in WRA	# of Turbines Searched	Search Interval	Total # Observed Fatalities	# of Raptor Fatalities	Reference
Altamont Pass, CA and Tehachapi, CA	<250 kW turbines	1984-1988	Not available	Incidental discoveries	Incidental discoveries	Raptor reports	63 (Alt) 9 (Teh)	California Energy Commission 1989.
Altamont Pass, CA	<250 kW turbines	9/88-8/89	~3000	359	2/week	42	18	Howell and DiDonato 1991.
Altamont Pass, CA	<250 kW turbines	4/90-3/91	~3000	150	2/week	10	1	Howell *et al.* 1991b.
Altamont Pass, CA	<250 kW turbines	1989-1991	7340	1169	1-2/week	182	74	Orloff and Flannery 1992.
Altamont Pass, CA	<250 kW turbines	1/1994	~7400	1169	One-time search	20	15	Orloff and Flannery 1996.
Altamont Pass, CA	KVS –33 & 56-100	12/93-8/95	~7400	165	2/week	72	44	Howell *et al.* 1997.
Altamont Pass, CA	mostly <250 kW turbines	4/98-3/00	~5000	785	1/5 weeks	256	117	Thelander 2000, pers. comm.
Montezuma Hills, CA	<250 kW turbines	4/90-5/92	600	237	Weekly	22	14	Howell and Noone 1992.
Montezuma Hills, CA	KVS –33 & 56-100	11/94-9/95	617	76	2/Week	13	10	Howell *et al.* 1997.
San Gorgonio, CA	<250 kW turbines	1985	Not available	Not available	Not available	38	1	McCrary *et al.* 1986a.
San Gorgonio, CA	mostly <250 kW turbines	3/97-5/98	~3750	~360	Quarterly	42	7	Anderson 2000a, pers. comm.
Tehachapi Pass, CA	mostly < 250 kW turbines	5/95-5/98	~5000	640-760	Quarterly	147	46	Anderson 2000b, pers. comm.

Source: Erickson et al. 2001.

[a] Types of fatalities included often vary by study. For example, in some studies, feather spots are included or electrocutions are included. In other studies only fresh carcasses that are likely turbine kills are included. Sometimes incidental discoveries are included; other times they are not.

Table 2. Wind Turbine Fatality Rate Estimates from Studies Conducted in the United States.

Study Area	State	Reference	Seasons	Dates	Turbines in study	Turbines in WRA	# bird fatalities /turbine/yr.	# raptors /turbine/yr
California								
Altamont Pass[b]	CA	Howell and Didonato (1991)	All	9/88–8/89	359	7340	na[a]	0.050
Altamont Pass[b]	CA	Howell and Didonato (1991)	All	9/90–8/91	150	7340	na[a]	0.007
Altamont Pass[b]	CA	Orloff and Flannery (1992)	All	89–90	1169	7340	na[a]	0.058
Altamont Pass[b]	CA	Orloff and Flannery (1992)	All	90–91	1169	7340	na[a]	0.023
Altamont Pass[b]	CA	Thelander (2000) pers. comm.	All	99–2000	685	5400	na[a]	0.100
Montezuma Hills	CA	Howell and Noone (1992)	All	4/90–5/92	237	600	na[a]	0.033
San Gorgonio	CA	McCrary *et al.* 1986a	All	1985	Not available	2947	2.307	na[b]
Outside California								
Buffalo Ridge (Phase I)	MN	Osborn *et al.* (2000)	All	1/95–12/95	50	73	0.493	0.000
Buffalo Ridge (Phase I)	MN	Johnson *et al.* (2000b)	all but winter	3/96–11/99	21	73	0.980	0.012
Buffalo Ridge (Phase I)	**MN**				**Weighted average (by years)**		**0.883**	**0.010**
Buffalo Ridge (Phase II)	MN	Johnson *et al.* (2000b)	all but winter	3/98–11/99	40	143	2.270	0.000
Buffalo Ridge (Phase III)	MN	Johnson *et al.* (2000b)	all but winter	3/99–11/99	30	138	4.450	0.000
Buffalo Ridge Overall	**MN**				**Weighted average (by turbines)**		**2.834**	**0.002**
Foote Creek Rim (Phase I)	WY	Johnson *et al.* (2001)	All	11/98–10/00	69	69	1.750	0.036
Green Mt., Searsburg	VT	Kerlinger (1997)	summer, fall	6/97–10/97	11	11	0.000	0.000
IDWGP, Algona	IA	Demastes and Trainer (2000)	fall, winter, spring	10/98–6/99	3	3	0.000	0.000
Ponnequin	CO	Kerlinger (2001) pers. comm.	All	11/98–11/00	29	29	na	0.000
Somerset County	PA	Kerlinger (2001) pers. comm.	All	6/00–1/01	8	8	0.000	0.000
Vansycle	OR	Erickson *et al.* (2000b)	All	11/98–10/99	38	38	0.630	0.000

Source: Erickson et al. 2001.

[a] Although all bird estimates reported, no scavenging or searcher efficiency conducted for small birds (e.g., passerines).

[b] Not applicable.

4.1.1.2 Studies in the United States Outside of California.

Fatality studies in the United States at sites outside of California have indicated that the incidence of raptor collisions in California, particularly at the Altamont Pass WRA, is considerably higher than in other WRAs. In a comprehensive survey of avian fatality studies, Erickson et al. (2001) found that out of 11 studies in eight states outside of California, there was a total of 204 reported bird fatalities and only six of these were raptors (see Table 1).

Passerines composed the highest percentage of fatalities in the non-California studies (see Table 2). Reports from these studies suggest that the levels of fatalities are not likely significant enough to threaten local or regional population levels (Kerlinger 1997, Johnson et al. 2000a; 2000b, Curry and Kerlinger 2000, Erickson et al. 2000, Osborn et al. 2000).

A major difference between the Altamont Pass WRA and other WRAs is that many other areas lack the dense populations of raptors and diverse topography of the Altamont Pass WRA. The high number of fatalities at the Altamont Pass WRA has served to create awareness of potential siting problems and in some cases, more regard has been given to the level of avian use prior to construction. (Strickland pers. comm.; Sinclair pers. comm.). For example, at the Foote Creek Rim WRA in Wyoming, the wind plant was constructed using some of the management methods thought to reduce risk to raptors. The turbines were constructed using tubular towers and underground electrical service when possible, thereby reducing potential perching sites. The developer also designed the wind plant to avoid high eagle-use areas by siting the turbines slightly away from the rim edge of a flat table top mesa. (Strickland et al. 2001).

This lower raptor fatality rate at other sites may also be related to the fact that older sites, such as those in California, were built on larger parcels with many small turbines placed at much higher densities than they are the newer WRAs. For example, the Altamont Pass WRA currently contains approximately 5,400 wind turbines—most of which have a rated capacity below 250 kW—while the Buffalo Ridge WRA in Minnesota consists of approximately 400 wind turbines, most of which are rated at 750 kW (see Table 1). Another possible (but unsubstantiated) effect is that wind turbine facilities located outside of California generally allow a much greater distance between turbines and feature design characteristics such as increased rotor blade height, reduced rotational and tip speeds, and larger overall turbine size—which may contribute to a reduced risk for some avian species.

4.1.1.3 European Studies.

Studies on avian interactions have been conducted at over 100 sites in Europe, but most of these studies focus on solitary or small groups of turbines. As a result, it is difficult to compare data with U.S. studies that focus on larger groups of turbines. Also, the European studies were based on coastal sites where waterfowl and migratory bird issues did not yield results comparable to California studies (Winkelman 1995). Musters et al. (1991) and

Winkelman (1995) showed that fatality rates varied between 0.01. and 0.09 birds per turbine per day or 3.7 to 32.9 per turbine per year, depending on site and season. In a summary of avian impacts at wind turbines by Benner et al. (1993) bird deaths per turbine per year were as high as 309 in Germany and 895 in Sweden.

Although these numbers represent much higher rates of fatality than those that occur in California and the rest of the United States, many European scientists have not considered this impact a significant threat to bird populations in most of Europe for a number of reasons:

- The number of deaths is small relative to the total number of birds using or passing through the area.
- The number of victims is small compared to the number of victims of other unnatural causes of deaths.
- Species included relatively common species of passerines and waterbirds, not raptors.
- European wind farms typically contain few turbines (Crockford 1992; Benner et al. 1993; Winkelman 1995).

The exception may be in Tarifa, Spain where a large number of protected species have been killed including raptors and storks (Winkelman 1995). No specific study results from this site are available for comparison with California WRAs.

4.1.2 Population Effects of Fatalities at Wind Plants

Very few studies have been performed to determine the overall effects of wind turbine impacts on the population viability of an individual species. This type of evaluation is exceedingly difficult and relatively costly; studies that are based on field-level tracking of population parameters require intensive sampling over a number of years for each species of concern (Morrison and Pollock 1997).

Most evaluations of wind-turbine-related avian fatalities have concluded that the impacted birds are fairly common and not threatened at the population level. For example, McCrary et al. (1986) estimated that as many as 6,800 birds, mainly passerines, were killed annually at the San Gorgonio WRA, but also concluded that the fatalities were relatively insignificant when compared to the estimated 69 million birds migrating through the area each year. Johnson et al. (2000c) found a relatively low wind-turbine-related fatality rate for common, resident breeding birds and indicated that there would likely be no population consequences within the Buffalo Ridge, Minnesota WRA. Winkelman (1995) concluded that though the Netherlands had some of the highest per-turbine fatality rates in the world, this was not a significant biological problem for bird populations, because the species that were killed were primarily common waterfowl and shorebird species.

Because some raptor species are relatively less abundant and produce fewer young, compared with many other groups of birds, human-caused fatalities could have a more noticeable effect on populations. Several species of raptors, such as golden eagles and burrowing owls (*Speotyto cunicularia*) have relatively high fatality rates at the Altamont Pass WRA in relation to their estimated abundance.

4.1.2.1 Golden Eagles.

Concern has been directed at the impacts on raptor species (particularly the golden eagle) at the Altamont Pass WRA, where Hunt (2002) estimated that wind turbines kill an average of 40–60 eagles each year. One of the largest known concentrations of breeding golden eagles in the world exists within 20 miles of the Altamont WRA (Hunt 2002). This species occurs in relatively low numbers and is slow to mature and reproduce; consequently, high fatality rates due to wind turbine impacts could threaten regional population levels. Statewide populations have declined, especially near human population centers (Remsen 1978). The golden eagle is also protected under the Migratory Bird Treaty Act and the Bald and Golden Eagle Protection Act.

Funded by the National Renewable Energy Laboratory (NREL) and California Energy Commission's PIER program, the Predatory Bird Research Group (PBRG) conducted a seven-year study to determine the extent to which eagle deaths resulting from wind turbine blade strikes were influencing the trend of the population (Hunt 1995; Hunt et al. 1998; Hunt 2002). Their population model provided an estimate of no annual change in population size. The vast majority of golden eagle deaths were subadult and floaters (nonbreeding adults), but because nesting territories remained occupied and productive, the fatality rates from wind turbine deaths alone were not affecting the population to the point where Hunt (2002) was able to detect or predict a decline. Hunt (2002) cautioned that continued land conversion around the WRA and wind-turbine-caused fatalities could contribute to population declines in the future.

4.1.2.2 Burrowing Owls.

Recent fatality data from Thelander and Rugge (2001) indicates that burrowing owl collision rates are higher at the Altamont Pass WRA than previously recorded. They reported a high number of fatalities per owls observed from March 1998 through December 2000. Thelander and Rugge indicated that this species is declining in California and that this level of fatalities could significantly impact local populations, therefore, they recommended further study.

4.1.2.3 California Condors.

There is currently a proposal by the Ventana Wilderness Society in conjunction with the U.S. Fish and Wildlife Service to conduct releases of California condors (*Gymnogyps californianus*) in the Hamilton Range of the Diablo Mountains (Davis and Sorenson 2001). The California condor is a fully protected endangered species in California and some concern has been expressed that these condors could potentially interact with the Altamont Pass and other WRAs; released condors have died after colliding with transmission lines. Davis and Sorenson (2001) speculated that since turbine fatalities are rare in turkey vultures, a low fatality rate might be expected. They state that pre- and post-release aversion training, along with other measures such as removal of condors that have habituated to the vicinity of WRAs, would be necessary.

4.1.3 Causes of Fatalities

4.1.3.1 Birds at Risk.

Within California, particularly at the Altamont Pass WRA, raptors are more susceptible to collisions with wind turbines than other species. Orloff and Flannery (1992, 1996) first reported that golden eagles, red-tailed hawks and American kestrels (*Falco sparverius*) were killed more frequently than were turkey vultures and common ravens (*Corvus corax*), even though the latter two species were more abundant. More recent surveys at the Altamont Pass WRA (Thelander et al. 2001a) and the San Gorgonio and Tehachapi WRAs (Anderson pers. comm.) have confirmed this. Heavy collision fatalities of migratory raptors, including Griffon vultures (*Gyps fulvus*), have also been reported at Tarifa, Spain (Gill and Townsley 1996).

Outside California, passerines, mainly nocturnal migrants, comprise the highest percentage of fatalities. European studies have also indicated that ducks and waders are more likely to collide than other types of birds. Fatality data from Vansycle Ridge, Oregon, indicate that passerine migrants appear most prone to turbine collisions (Strickland et al. 2001). Migratory birds tend to fly at altitudes of 500 ft (150m)—well above the average height of wind turbines (200–350 ft; 60-100m). However, poor weather can reduce migration altitudes and put birds at greater risk (Crockford 1992, Colson 1995a, Winkelman 1992 from Gill and Townsley 1996, Johnson et al. 2000c). Within migratory flyways, large numbers of passerines have been recorded flying at an altitudinal zone of risk (McCrary et al. 1983). Topographical features, such as ridges that decrease the altitude of birds relative to ground level, may result in a higher collision risk although recent studies have not demonstrated this ridge effect.

4.1.3.2 Bird Behavior.

The relatively high diversity of bird species suggests a variety of perching and flight behavior, and therefore, underlying risk factors associated with wind turbines vary greatly from species to species (Thelander and Rugge 2000). Studies of birds approaching turbines show that most birds pass over or through turbine structures avoiding collisions (Winkelman 1992, Rogers et al. 1997, McCrary et al. 1984, Orloff and Flannery 1992, Kenetech 1995). Some birds, however, may be more prone to collision with turbines for a variety of reasons. For raptors, flight and hunting behavior require that they often fly at low altitudes and may strike turbines while searching or stooping for prey. Orloff (1992) reported that 33 percent of raptors observed at the Tehachapi WRA and 39 percent of raptors observed at the Altamont Pass WRA flew at turbine height. Hunt (2002) suggests that golden eagles hunting by wing, rather than from a perch, are at greater collision risk. In contrast, no fatalities (or very few) were recorded for northern harriers (*Circus cyaneus*), which frequently hunt below the 9 m minimum blade height; or common ravens and turkey vultures, which eat primarily carrion (Orloff and Flannery 1992, Thelander and Rugge 2000).

Studies by Hunt (2002) and Orloff and Flannery (1992) suggest that the abundance of California ground squirrels (*Spermophilus beecheyii*) may significantly increase foraging activity of some raptors and thus collision risk, in the Altamont Pass WRA. Hunt (2002) found a significant correlation between golden eagle radio-telemetry locations and areas with high squirrel densities. Smallwood et al. (2001) found that the number of dead hawks at turbine strings increased with increasing proximity and density of pocket gophers (*Thomomys bottae*) and ground squirrels.

Age or breeding status may also be a risk factor associated with bird fatalities. Immature golden eagle and red–tailed hawk fatalities occurred more often than would have been predicted from their abundance at the Altamont Pass WRA (Orloff and Flannery 1992). The researchers suggested that this phenomenon could be attributed to the inexperience of younger birds. However, Hunt (2002) found that most golden eagle mortalities were not juveniles, but subadults and non-breeding adults. This difference may be due to the fact that Orloff and Flannery (1992) did not separate juveniles and subadults into separate age classes. Therefore, data on an association between inexperience and fatality rate are inconclusive for golden eagles. Hunt (2002) attributed the higher fatality rate of subadults and non-breeding adults to the greater amount of time they spend foraging in the WRA, compared to breeding adults; breeding adults did not venture from their territories, which were predominately located outside of the Altamont WRA.

4.1.3.3 Turbine Design.

Several different wind turbine types are used at a number of the large California WRAs, such as Altamont Pass, San Gorgonio, and Tehachapi. Various design features, such as perch availability, rotor diameter, rotor-swept area, rotor height, rotational and tip speeds, and fixed versus variable turbine speed have been evaluated to determine if they contribute to bird collision risk.

Perch Availability. Orloff and Flannery (1992, 1996) concluded that bird fatalities were significantly higher at horizontal lattice-tower turbines than at any other type. These tower types have a greater number of horizontal structural supports than other designs (e.g., diagonal lattice and tubular) that provide less-suitable perching structures. Hunt (1995) observed that some raptors avoid perching on tubular towers and suggested that conversion to tubular towers would decrease collision fatalities. Hunt (2002) also found that one type of horizontal lattice turbine (Kenetech 56-100 with a 18.3 m [60 ft.] tower height) was responsible for 73 percent of the deaths that could be assigned to specific wind turbines. Although statistical evaluation suggested that the relative abundance of this type of turbine was sufficient to explain its high association with eagle fatalities, he suggested that other factors associated with this particular type of turbine could also explain their higher lethality. These included the shorter height (which has blades rotating closer to the ground), the shorter distance between turbines (which affords less spacing between blades), and the lack of a ground squirrel eradication program in the vicinity.

A recent study by Thelander and Rugge (2000) indicates that tubular turbines present a high risk to birds at the Altamont Pass WRA. Fifty-seven percent of their bird fatalities were associated with tubular towers (which provide little or no available perch space) even though they constituted 50 percent of the turbines in their fatality searches. Although their reported fatality rates for tubular turbines in some cases exceed previously reported rates for horizontal lattice turbines, their earlier surveys did not include horizontal lattice towers for comparison. Results from a greater diversity of tower types are currently being analyzed (Thelander pers. comm.). In addition, data analysis of fatality surveys at San Gorgonio and Tehachapi indicates no significant difference between lattice and tubular turbine towers, although these studies only included diagonal—not horizontal—lattice turbines. (Anderson pers. comm.).

Rotor Diameter and Rotor-Swept Area. Orloff and Flannery (1992, 1996) found no conclusive evidence that increased rotor diameter or rotor-swept area in the Altamont Pass WRA were associated with fatalities. Their analysis was limited, due to the small range of rotor sizes (up to 18 m, or 59 ft.) that were evaluated. Anderson (pers. comm.) found no difference in fatality rates between smaller (22-m) and larger (26-m) turbines in San Gorgonio and Tehachapi WRAs. Thelander and Rugge (2001) reported that the number of fatalities increased with the increased rotor-swept area in a turbine string. They also found an increased number of red-tailed hawk, golden eagle, burrowing owl and barn owl fatalities—but not American kestrel fatalities—associated with the two largest-diameter rotors within their Altamont Pass WRA study site. The studies however, did not attempt to determine if the increase in fatalities was proportional to the increase in rotor-swept area. Also absent from all these studies was any adjustment to changes in operational time or energy efficiency.

Tucker (1995a, 1995b) concluded that birds had much lower probabilities of colliding with larger, variable-speed rotors (KVS-33; 33 m, or 108 ft.) than the smaller, fixed-speed rotors (KCS-56; 18.5 m, or 61 ft.). His analysis, using mathematical models, was based on the theory that birds would be less likely to collide with the larger turbines because of their higher conversion efficiency; the blades would be rotating at a slower rate of speed for a given wind velocity. If all other factors remained the same, increased blade length would not increase the number of bird collisions. Tucker concluded that if the smaller turbines were replaced with sufficient numbers of the larger turbines to generate the same amount of electrical energy in a year, the result would be a two-thirds reduction in avian fatalities.

Howell (1997) compared a series of the KCS-56 turbines with KVS-33 turbines under the hypothesis that a larger KVS-33 turbine, which sweeps 3.46 times the area the smaller KCS-56 turbine, would cause 3.46 times the raptor fatalities of the KCS-56 turbine. He found that the larger rotor-swept area of the KVS-33 turbines did not result in a higher fatality rate. The per-turbine fatality rate was 0.278 for KVS-33 and 0.264 for KCS-56 turbines, or 1.05 times greater fatality rate at the KVS-33 turbines even though it sweeps slightly more than three times the area as a KCS-56 turbine. The newer generation turbines are considerably larger than either of these two turbines mentioned above.

The issue of rotor-swept area and blade diameter effects on avian collision risk with turbines is important because wind developers are in the process of repowering or replacing existing, less efficient turbines with a smaller number of new, larger, and more efficient turbines (see Section 4.1.4). Under the proposed repowering program, 5,352 turbines would be removed and replaced with a total of 908 turbines. Total rotor-swept area would be similar, but rotations per minute, tip speed, operational time, and other factors would be different (see Section 4.1.4). Three specific proposals for the Altamont Pass WRA that have received certification under the California Environmental Quality Act include the replacement of 1,272 wind turbines with no more than 187 new ones (Alameda County 1998).

Rotational Speed and Tip Speed. Orloff and Flannery (1996) found that rotor velocity and a corresponding increased tip speed is correlated with fatalities. Thelander and Rugge (2001) found that faster turbine rotor speeds killed more red-tailed hawks, golden eagles, burrowing owls, and barn owls than would be expected by chance.

Rotor Height. Orloff and Flannery (1996) found no statistically significant correlations between turbine height and fatalities. However, their study did not include taller turbines placed in the Altamont Pass WRA in the latter half of the 1990s. In their Altamont Pass WRA study that included turbines with rotor centers that ranged from 14 to 43 m (46 to 141 ft.) in height, Thelander et al. (2001) found that towers with rotor centers of 24 m (79 ft.) in height killed more red-tailed hawks, golden eagles, American kestrels, burrowing owls, and barn owls than would be expected by chance. Hunt (2002) found that the Kenetech 56-100 turbine on an 18.3-m (60-ft.) lattice tower killed 73 percent of the radio-telemetered eagles killed by wind turbines in the Altamont Pass WRA. He speculated that these fatalities might be in part attributable to the relatively short tower height that allowed the rotor blades to pass closer to the ground than 95 percent of the other turbine types.

At the Buffalo Ridge WRA in Minnesota, daytime flight height surveys by Johnson et al. (2000c) reported a significantly higher proportion of flight observations within the rotor-swept height of the shorter of two turbine types. Fatalities of all bird species, however, were higher at the taller turbines. This was attributed to higher-flying, non-raptor nocturnal migrants that constituted the greatest percentage of fatalities.

Behavior differences among raptors indicate that there may be some trade-offs in benefits. For example, one species may benefit from blade tips being further from ground level, whereas others may be exposed to greater risk from blades that reach a greater overall height.

Variable vs. Fixed-Speed Turbines. Researchers have performed very little research to examine the effects of variable vs. fixed-speed turbines on avian fatalities. Orloff and Flannery (1992) did not find a statistically significant correlation between collision fatalities and fixed versus variable turbine speeds. Newer turbines in the Altamont Pass repowering areas will be variable-speed versions, and since most of the previously installed turbines in the WRA were fixed-speed versions, this design factor may contribute to a difference in collision risk. Whether this risk would be higher or lower is subject to speculation; however, this characteristic does allow the turbines to be operated more of the time, because they can operate during a greater range of wind speeds. Although the maximum tip speeds of the newer variable-speed turbines are comparable to the fixed-tip speed of the majority of existing turbines, their average tip speed would be considerably slower.

4.1.3.4 Wind Plant Design.

Spatial Arrangement of Turbines. The association between spatial distribution of wind turbines and fatality rates has been evaluated at a variety of sites. However, variation in site characteristics and turbine arrangement and design at WRAs has made it difficult to derive conclusive patterns. Because flight lines often follow prevailing wind directions, the placement of turbines in optimum position and orientation for wind energy capture may result in obstacles directly in the path of local and migratory birds (Colson 1995a). Winkelman (1992) found that fewer birds collided with the middle row of turbines in the Netherlands and recommended that turbines be placed either in a dense cluster parallel to the main migration direction or in an open cluster. Orloff and Flannery (1992) found significantly higher fatality rates of all species at relatively lower density turbine arrays and arrived at the possible conclusion that higher-density arrays may be more effective at excluding birds. Hunt (2002) indicated that turbines spaced close together caused collisions by making it more difficult for golden eagles to clear the space between blades. Finally, Thelander et al. (2001) found a significant positive correlation between the number of raptor fatalities and the number of wind turbines in a string. There was no indication in this study however, if the increase in fatalities was proportional to the number of turbines in a string.

Orloff and Flannery (1992, 1996) found significantly higher collision fatalities at end-of-row turbines than within-row turbines. They speculated that end-of-row turbines may have a higher fatality rate because of their proximity to canyons. Wind speeds are usually higher and raptors probably hunt more near canyons or draws, using topography for contour hunting and slopes winds for lift. However, Howell and Noone (1992) did not find end-of-row turbines to be statistically more likely to contribute to fatalities—rather, they found that collisions appeared to be randomly distributed along rows of turbines. Thelander and Rugge (2000) and Anderson (pers. comm.) did not find a significant difference between frequencies of fatalities associated with turbines at the ends of strings compared to those in the middle of strings at Altamont or San Gorgonio WRAs, respectively.

Irregular spacing, where wider than average gaps occur, may result in higher raptor fatality rates (Thelander pers. comm.). Data from Tehachapi and San Gorgonio indicate that a partial string of turbines separated by a larger-than-average gap from the rest of a turbine string kill birds at a higher rate (Anderson pers. comm.). Some of the end-of-row turbine/fatality association found by Orloff and Flannery (1992 and 1996) may be explained by this same irregular spacing pattern; in their studies, turbines within a single turbine string that had a wider-than-average spacing, were placed in the end-of-row category. Therefore, some of their end-of-row fatalities may have been categorized as "gap" fatalities in other studies (Orloff pers. comm.). The spatial characteristics of these terms (i.e., irregular spacing, gaps and end turbines) need to be strictly defined and standardized for future studies.

Topography. How turbines are placed in relation to specific topographic features within a WRA may have an effect on the frequency of bird collisions. Orloff and Flannery (1992) found consistently higher raptor fatality rates in areas where turbines were placed closer to canyons. Howell and Noone (1992) identified mid-row depressions (swales) and ridge-ends (shoulders) as features associated with avian fatalities. Thelander and Rugge (2001) found that wind turbines located in one of the three major canyons at the Altamont Pass WRA killed 1.8–3.6 times the number of red-tailed hawks, golden eagles, burrowing owls, and barn owls (*Tyto alba*) than would be expected by chance. Thelander and Rugge (2001) also found that turbines on ridge tops and swales killed more red-tailed hawks than expected, and towers on slopes killed more golden eagles. Johnson et al. (2000b) found a greater density of raptors near the rim of the plateau at the Foote Creek Rim, Wyoming, WRA than at the more interior portions and recommended moving the turbines from the rim to decrease the chance of collisions. Hunt (2002) could find no consistent relationship between terrain features and fatality rates. It has been suggested that the most dangerous turbines at Tarifa in Southern Spain seem to be those on high points of ridges, near night roost and frequented outcrops (Gill and Townsley 1996).

Ground Disturbance. Design and maintenance characteristics of road and structures may indirectly contribute to higher bird fatality rates by increasing prey densities. Orloff and Flannery (1992)—and more recently Smallwood et al. (2001)—suggested that vertical and lateral edges and other features associated with roads, turbine pads, and maintenance areas may create suitable burrow sites for raptor prey in the vicinity of wind turbines, with a corresponding increase in raptor foraging activity. Preliminary results from Smallwood et al. (2001) indicate that the occurrence of pocket gophers in the vicinity of wind turbines might be associated with the fatalities of many raptorial birds, especially red-tailed hawks.

4.1.3.5 Location of Wind Plant.

Early WRA developments did not adequately consider the potential impacts on birds. The Altamont Pass and Solano County WRA's were known to have a high density of raptors prior to placement of approximately 8,000 turbines (Colson 1995a, Howell and Noone 1992). In Europe, most wind farms were placed in coastal areas where seasonal concentration of water birds occurred (Gill and Townsley 1996). Placement of wind farms in the path of major migration routes was recognized as a potential hazard early in the planning of wind farms in southern California (McCrary et al. 1986), but the estimated fatality rate was considered small compared to the large number of passerines that passed through the San Gorgonio WRA. Fortunately, many wind farm sites in the United States have avoided waterfowl populations in wetland habitats, but some are located closest to natural valley passes where bird movements may result in temporary concentrations.

Avoiding areas with high bird use is the most effective siting consideration. Preliminary results from recent studies where risk reduction measures were used indicate that the efforts to avoid avian impacts by appropriate siting of particular turbines within a WRA have been successful (Sinclair pers. comm., Johnson et al. 2000b, Strickland et al. 2001).

Offshore wind facilities are being proposed in several locations in the eastern United States. This will require consideration of risk factors such as presence of daily and seasonal migration corridors for waterbirds. Height of turbines will also be a factor because they will be considerably taller than their current onshore counterparts. Navigation lighting and closer approximation in elevation to migratory bird routes may require different risk evaluation tools and methodologies than are currently employed on land.

4.1.4 Repowering

Alameda and Contra Costa Counties have initiated a repowering program at the Altamont Pass WRA (Alameda County 1998). Repowering refers to the replacement of existing, less-efficient turbines with a smaller number of larger, more-efficient turbines (see Figure 2). Replacement ratios will range from 7–10:1. The impacts of repowering on avian fatality rates, particularly raptors, have not been evaluated. The Environmental Impact Report, *Repowering a Portion of the Altamont Pass Wind Resource Area,* (Alameda County 1998) concluded that there was a potential for reduced risk with the incorporation of the new turbine design, because such a repowering would reduce the total number of turbines, replace lattice turbines towers with tubular towers, reduce rotational speed, and increase in tip distance from the ground. In addition, the majority of turbines would have an equivalent or reduced tip speed. There would, however, be an increase in operational time.

The following standards are required for the repowering projects in the Altamont Pass WRA:

- Reduce the number of turbines within each project area by limiting the total future amount of rated turbine capacity in the Altamont Pass WRA to existing levels.
- Limit the maximum rotation speed of rotors to 35 rpm.
- Permit only tubular towers with no perchable surfaces or appendages.
- Permit only interior tower access to eliminate exterior footsteps that would potentially serve as perch sites on towers.
- Permit only perch-proof nacelles (turbine generator covers).
- Site turbines according to specific siting criteria to avoid higher risk areas.

An important restriction of the repowering program is an interim limitation on development, which prohibits exceeding the existing level of rated capacity at Altamont (583 MW) until a reduction in avian fatalities has been demonstrated. The mitigation plan of the EIR requires a monitoring program to be "generally" consistent with the National Wind Coordinating Committee's guidelines for studying wind energy/bird interactions

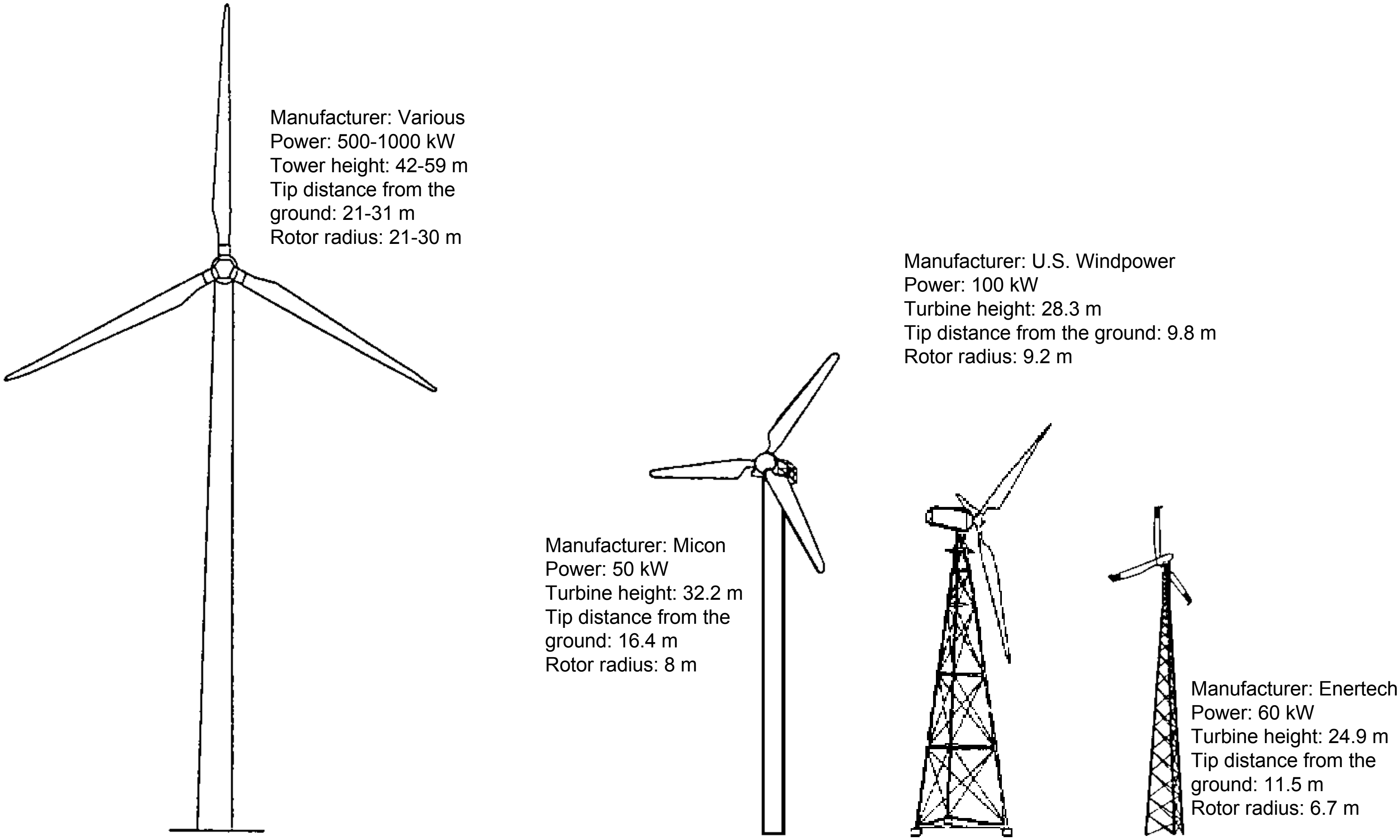


Figure 2. Comparison of size and other characteristics of three wind turbine types currently in operation at the Altamont Pass Wind Resource Area with a representation of proposed new and larger turbine that would replace them.

(Anderson et al. 1999) and states that monitoring "should include pre- and post-project surveys to evaluate onsite differences in bird behavior and fatalities"(Alameda County 1998).

4.1.5 Risk Reduction

The following is a discussion of known risk-reduction measures and changes in wind turbine features that have been employed or have been suggested, and an evaluation of their potential to reduce raptor fatalities. Because many potential risk-reduction features are included in the proposed repowering of the Altamont WRA, the potential effects of this program are discussed as well.

4.1.5.1 Perching Avoidance.

Howell (1995) modified 54 Kenetech lattice tower turbines in the Altamont Pass WRA by stringing a single strand of wire several inches above potential perching sites to prevent birds from landing. Results indicated that perching red-tailed hawks used the modified towers less frequently and for shorter durations than the control towers. There has been no published study to indicate whether this had a corresponding reduction in fatalities.

Curry and Kerlinger (2000) indicated that operators of the Kenetech horizontal lattice-type towers had developed an avian mitigation plan with an objective to eliminate perching and/or roosting activity. Under the proposed Altamont Pass WRA repowering plan, many of these same turbines would be eliminated and replaced with large tubular towers at a ratio of 7:1. Perch-proof nacelles will be installed as well.

4.1.5.2 Rotor Diameter and Rotor-Swept Area.

There is some conflicting evidence that increasing rotor diameter and consequently rotor-swept area may (Thelander et al. 2001) or may not (Tucker 1995a, Howell 1997) result in an increase in fatalities. Thelander et al. (2001), however, did not determine if the increase in fatalities was proportional to the increase in rotor diameter or rotor-swept area. The repowering effort would result in an overall reduction of *annual* rotor-swept area at the Altamont Pass WRA; annual rotor swept area is the area that one turbine rotor will sweep in a one-year period, taking into account average annual rotational speed (rpm), average annual percent operation time, and rotor diameter. In spite of an increase in the overall time that the new turbines would operate, a greatly reduced rotational speed would contribute to a reduced annual rotor-swept area. For example, a Micon 750-kW two-speed (22/15 rpm) turbine is proposed to replace the most common turbine in the Altamont Pass WRA—the U.S. Windpower 100-kW fixed-speed (72 rpm) turbine—at a ratio of 1:7. Even assuming an annual operating time increase of 55% and a constant maximum rotational speed of 22 rpm, the annual rotor-swept area of one Micon turbine would be 54% smaller than that of seven U.S Windpower turbines (Table 3). Under the same assumptions, the much larger Enron 1.5-MW variable speed (11–22 rpm) turbine would have a 67% smaller annual rotor-swept area than 15 U.S. Windpower turbines that provide equivalent power capacity (Table 3).

A more realistic assumption of average (rather than maximum) wind rotational speeds would result in even further reductions in annual rotor-swept areas of the newer turbines. Although actual average rotational speeds are not known, Table 3 provides a comparison of annual rotor-swept areas based on the assumption that, on average, they operate at the midpoint of their variable speed range. It is necessary to isolate the effects of increased rotor diameter and rotor-swept area from other factors, such as operational time and rotational speed, to fully evaluate the effects of these related characteristics.

4.1.5.3 Rotational Speed and Tip Speed.

No studies have been performed to test the hypothesis that a reduced rotational speed or tip speed would reduce avian fatalities. Alameda County (1998) concluded that replacing existing turbines with fewer, larger turbines with reduced tip and rotational speeds would be one of several factors that might reduce overall fatalities at the Altamont Pass WRA. Many of the turbines will have a rotational speed reduced by as much as 70 percent. In addition, although *maximum* tip speeds of the newer variable-speed turbines are comparable to the fixed-tip speed of the majority of existing turbines, their *average* tip speed would be considerably slower.

4.1.5.4 Rotor Height.

No studies have been performed to test the hypothesis that a change in rotor height (with a corresponding increase in blade height) would reduce avian fatalities. Due to their foraging behavior, some birds such as golden eagles and other raptors may be less at risk with turbine blades that sweep further from ground level. However, researchers need to determine whether or not the increased height would have a negative impact on birds with higher flight paths.

4.1.5.5 Variable Versus Fixed Turbine Speed.

No studies have been performed to test the hypothesis that a change from fixed-speed to variable-speed turbines would reduce or increase bird fatalities. The majority of turbines currently in operation in the Altamont Pass WRA are fixed-speed turbines. The variable speed features of newer turbines directly affect average tip speeds and annual rotor-swept area, as discussed above.

4.1.5.6 Spatial Configuration.

The relationship between spatial configuration of turbines and higher fatality risk, including impacts of end-of-row versus mid-row turbines, variation in gaps between turbines on a string, and clustering versus open configurations, remains uncertain. The newer turbines in the Altamont Pass WRA will be spaced at greater distances from one another. In terms of bird risk, this spacing may or may not cause each turbine to function as a more isolated unit and alter the end-of-row and gap effects. Whether or not this strategy will eliminate or increase bird risk is unknown.

Table 3. Comparison of annual rotor-swept areas between two newer, larger turbines and comparable energy equivalents of the most common wind turbine type in the Altamont Pass WRA (7 U.S. Windpower 100-kW vs. 1 Micon 750-kW, and 15 U.S. Windpower 100-kW vs. 1 Enron 1.5-MW).

Turbine Type	7 U.S. Windpower Turbines	1 Micon 750 kW		15 U.S. Windpower Turbines	1 Enron 1.5 MW Turbine	
	Fixed Rotational Speed	Average Rotational Speed	Maximum Rotational Speed	Fixed Rotational Speed	Average Rotational Speed	Maximum Rotational Speed
Rotor-swept area (sq. ft.)	19,792	19,359	19,359	42,412	32,878	32,877
Rotational speed (rpm)[a]	72	18.5	22	72	15.5	20
Estimated swept area per minute continuous operation (sq. ft.)	1,425,030	358,147	425,905	3,053,636	509,605	657,555
Estimated annual percent time of operation[b]	49	49	75	49	49	75
Total annual rotor-swept area (sq. ft.)	3.67E+11	1.41E+11	1.68E+11	7.87E+11	2.01E+11	2.59E+11
Annual decrease factor (compared to existing KCVS-100)	NA	0.38	0.46	NA	0.26	0.33

[a] The U.S. Windpower turbines operate at a fixed speed, the Micon is a two-speed turbine, and the Enron a variable-speed turbine. Average rotational speed for the Micon and Enron turbines used for this analysis is hypothetical and is the mid-point of each of the two rotational speed ranges. As there is a linear relationship between rotational speed and wind speed, the true averages would be based largely on the average wind speed of each individual site.

[b] Estimates of percent time of operation are based on estimates derived from Alameda County (1998) estimates for U.S. Windpower 100-kW turbines and similar turbines proposed for repowering at the Altamont Pass WRA. The increased operation time of new turbines is attributable to lower cut-in and higher cut-out speeds and other factors.

4.1.5.7 Visual Treatments.

Lighting. Lights seem to play a key role in attracting birds and the lighting of tall structures appears to contribute to avian fatalities. Although there does not appear to be a high number of fatalities caused by lighted wind turbines (Anderson pers. comm.), illuminating other taller aerial structures in the United States to make them more visible to aircraft has resulted in increased bird fatalities (CEC 1995; Colson 1995a). Migratory species generally migrate at night and appear to be most susceptible to collisions with lit towers on foggy, misty, rainy, low-cloud-ceiling nights during their migrations, particularly nocturnal migrants such as passerines during poor visibility conditions. Solid or blinking red lights seem to attract birds on foggy, misty nights more than white strobes, which may flash every 1–3 seconds. Preliminary research suggests that the longer the duration of the "off" phase, the less likely a light is to attract birds (Manville 2001). Byrne

(1983) pointed out that illumination of turbines might lead to elevated collision risk. However, Byrne (1983) also indicated that stroboscopic illumination might reduce bird activity in the vicinity of turbines, but this has not been tested.

Blade Painting. Some research has been performed under laboratory and field conditions to determine the visual acuity and capacity of raptors to see wind-turbine blades. McIsaac (2001) found that under laboratory conditions raptors might not see turbine blades under some environmental conditions. His tests on American kestrels found that applying high-contrast patterns to turbine blades may increase the birds' ability to distinguish individual blades.

Hodos et al. (2001) found that motion smear, which makes the blade tips of wind turbines appear transparent to birds at high speeds, could be reduced under laboratory conditions. Their preliminary results suggested that a single, solid-black blade, paired with two white blades (inverse blade pattern) could be effective at reducing visual smearing of blades. These results however, were under conditions that provided an artificial, high-contrast background. McIsaac (2001) found that using a blue-gray background significantly reduced a birds' ability to discriminate the inverse blade pattern and suggested that such a pattern could be rendered ineffective under field conditions. Current research involves testing simulated WRA backgrounds to determine which patterns and colors may be most appropriate for field conditions (Hodos pers. comm.) Hodos (2001) also noted that motion smear and a very narrow blade profile encountered when approaching from the side could be very risky for birds and suggested a rectangular attachment to the outer tip at right angles to the long axis of the blade. The visibility and practicality of these attachments has not yet been evaluated.

Howell et al. (1991) conducted a field study consisting of a randomly selected sample of 25 turbines with blades painted an alternating pattern of red and white and 50 control turbines at the Altamont Pass WRA. Preliminary results indicated fewer bird fatalities at turbines with painted rotors but the small sample size precluded any definitive conclusions. Strickland et al. (2001) tested the hypothesis that under field conditions, UV light would improve a diurnally active bird's ability to see wind turbines coated with a UV-reflecting covering. Preliminary results indicate that UV-coated turbine blades have no advantage over non-UV-coated turbine blades (Strickland pers. comm.) McIsaac (2001) suggested that one explanation for this outcome was that a uniform UV color against a high UV background such as the sky, might actually reduce the blade's visibility.

Changes in turbine characteristics. Newer turbines have a few characteristics that may decrease motion smear in birds, relative to older turbines, and consequently may reduce the fatality risk to some bird species. In general, turbine blades on new turbines are considerably larger and wider than older turbines. In addition, some of these turbines will have slower average tip speeds. Both of these characteristics may contribute to reduced motion smear (Hodos et al. 2001). Research should evaluate the relative effectiveness of these changes as compared to the use of smear-reducing blade patterns.

4.1.5.8 Auditory Treatments.

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 (Erickson et al. 1999). Most studies of auditory warning devices have found that birds become habituated to these devices (Erickson et al. 1999). Dooling and Lohr (2001) indicated that birds do not hear as well as humans and that 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. They suggested that under certain conditions (e.g. high wind) birds might lose their ability to see a turbine blade before they are close enough to be able to hear the blade. At present there is no research under way that tests the effects of auditory deterrents, and because of the low likelihood of developing a successful application, none is planned for the foreseeable future.

4.1.5.9 Remove Problem Turbines.

Thelander et al. (2001) reported that for a sample of about 1000 turbines studied in the Altamont Pass WRA, 25 percent of the turbines were responsible for 100 percent of the fatalities recorded. Erickson (pers. comm.) however, performed a simulation indicating that this distribution of fatalities could occur by chance alone. Nevertheless, certain physical and topographical factors appear to contribute to an increased collision risk. BioResource Consultants is currently using this information to develop a risk assessment model to rank turbines and the physical locations of turbines in terms of their risk to birds. The model could be used to modify or remove high-risk turbines and applied during the current repowering projects at the Altamont Pass WRA, to help site the location of replacement turbines.

Curry and Kerlinger (2000) indicated that an Avian Mitigation Plan for Green Ridge Services included evaluating high-risk turbines, using risk-avoidance siting criteria for future repowering projects, and applying risk-producing measures such as application of perch guards and audio and visual cues. It is not known if any of these measures have been employed or whether they have been effective, because no reports have been distributed. The Alameda County EIR (1998) states that siting standards will be used to site high-risk turbines for the Green Ridge Power project site, but the repowering program has not yet begun.

4.1.5.10 Operational Time.

Decreasing operation time of problem turbines or WRAs has been suggested as a risk reduction measure (Crockford 1992, Orloff and Flannery 1992, Gill and Townsley 1996). Critical shutdown times could be seasonal (e.g., during migration periods), or based on inclement weather or nighttime periods when visibility is reduced. This measure has not been employed and the wind industry would not consider it economically desirable. Sinclair (pers. comm.) suggests that economic consequences of any kind of adjustments to operation time should be considered prior to construction of a site so that the developer can make a feasibility assessment. Most of the newer wind turbines in the Altamont Pass repowering areas will increase operation time by as much as 55 percent (Alameda County 1998).

4.1.5.11 Reduce Quality of Habitat.

The density of raptors at the Altamont Pass WRA is, at least in part, a result of high prey availability. San Gorgonio and Tehachapi WRAs have lower prey densities, lower raptor densities, and lower per-turbine fatality rates (Anderson pers. comm.). Prey densities appear to be highest at disturbed sites such as roads and turbine pads, the latter of which would exacerbate collision risk.

Both Hunt (2002) and Smallwood et al. (2001) suggested that reducing prey populations within the vicinity of wind turbines might reduce high-risk foraging activities for raptors. Suggested methods include county-sponsored abatement programs, reduced grazing intensities, and revegetation with higher-stature plants that pocket gophers and ground squirrels tend to avoid. These measures, however, could impact other populations—including special status species such as the San Joaquin kit fox, burrowing owl, and badger. Smallwood et al. (2001) suggested that where high densities of gopher burrowing systems are found, controlling populations in the immediate vicinity of wind turbines could be effective. They cautioned, however, that small mammal abatement efforts by ranchers in surrounding areas could exacerbate the effect of burrow clusters in the vicinity of turbines by increasing the focus of raptor foraging. This effect occurs when there is rapid recolonization and higher-than-average densities of gophers on edges of abatement areas. Research would have to evaluate reduced grazing or revegetation with higher-structure plants would have to be evaluated to determine its effects on fire management, watershed protection, and other land-management practices.

If complete repowering of the Altamont Pass WRA were to occur, there would be an estimated 5,352 existing turbines removed and installation of up to 866 new turbines (Alameda County 1998). This would result in a net reduction in linear footage of roads and area occupied by turbine pads. A corresponding decrease in human-enhanced prey habitat could be expected.

4.1.5.12 Avoidance.

Recognition of the potential avian fatality risk has influenced the selection criteria used in developing some new WRAs in the United States (Anderson pers. comm., Strickland pers. comm.). Along with providing a framework for the development of more robust experimental field design, use of standardized protocols (Anderson et al. 1999) has greatly enhanced researchers' ability to compare and analyze data among studies from various WRAs (see Section 4.1.7). The evaluation of the level of bird use along with a determination of fatality rates allows for the assessment of relative risk at each site. By comparing these figures among sites, it may be possible to develop thresholds of bird densities that would be unacceptable for wind energy development.

The National Wind Coordinating Committee's Siting Subcommittee also produced a handbook in 1998 to address wind generation siting and permitting issues. In this document, they recommend measures to avoid potential high-risk areas, including a preliminary biological reconnaissance of each potential site and the use of standardized study, such as those outlined by Anderson et al. (1999), to ensure compatibility with other studies.

4.1.6 Habitat Impacts

Relative to other forms of energy development, wind farms occupy a large amount of space. WRAs in the western United States have been placed primarily in open habitat where they coexist with farming, ranching, and other low-intensity land uses. Wind farms may facilitate retention of semi-natural habitat where these low-intensity uses occur, resulting in long-term benefits for bird populations. Habitat that has been affected consists primarily of raptor-foraging habitat and nesting habitat for ground-nesting birds. The few trees and shrubs on these sites have been left undisturbed (Colson 1995a).

Orloff (1992) estimated that approximately 5–10 percent of potential bird foraging, nesting, and roosting habitat is removed for turbine pads and roads. Newer facilities that are built with larger, more-efficient turbines require fewer roads and have a greater amount of space between them. In addition, many of the newer facilities have their transmission lines placed underground, greatly reducing the likelihood of wire collisions and electrocutions (Sinclair pers. comm., Strickland pers. comm.).

Studies that have been conducted in the United States on habitat disturbance have yielded mixed results. Howell and Noone (1992) found similar numbers of raptor nests before and after construction at the Montezuma Hills WRA. A study by Johnson et al. (2000c) at the Buffalo Ridge WRA in Minnesota found that following wind turbine construction, there was a small-scale reduction in habitat use in 7 of 22 grassland-breeding birds. They found no overall (large scale) reduction in habitat use of the wind resource area and concluded that the small-scale impact was relatively minor. However, Leddy et al. (1999) surveyed bird densities in Conservation Reserve Program grasslands at the Buffalo Ridge WRA and found that mean densities of 10 grassland bird species were four times higher at areas located 180 m (590 ft.) from turbines versus those in grasslands nearer to turbines. They attached importance to these reduced densities because of regional concern for the decline of Midwestern grassland passerine species in response to agricultural tillage, grazing, and invasive woody species.

Habitat loss and disturbance effects of wind farms have been of greater concern and focus in Europe than avian collisions with wind turbines (Winkelman 1995). This is partly due to the fact that wind farms in Europe are relatively small (fewer than 10 turbines) as compared to U.S. sites. In the Netherlands, habitat loss and disturbance effects on primarily shorebirds were demonstrated at distances up to 250–500 m (820–1640 ft.) from the nearest turbines, depending on species, site, season, tide, and whether the wind park was in operation (Crockford 1992). The reduction in total numbers of birds in disturbed zones ranged up to 95 percent. Some studies have had mixed results on impacts to breeding birds, and some effects on flight patterns of migrating birds have been observed. Crockford (1992) noted that the displacement of migrating birds was unlikely to have a significant impact on individuals or populations.

4.1.7 Research Design Protocols

The National Wind Coordinating Committee (NWCC), a collaborative of representatives from the environmental community, wind energy industry, state legislatures, state utility commissions, consumer advocacy offices, green power marketers, and federal and state governments, was established in 1994 to support the development of wind power. The NWCC Avian Subcommittee was formed to address avian interactions with wind developments, and it identifies research needs and serves as an advisory group. To address differences in methodologies, lack of good experimental design in existing studies, and the resulting lack of inter-study comparability, the Avian Subcommittee developed a guidebook titled *Studying Wind Energy/Bird Interactions: A Guidance Document* (Anderson et al. 1999). The document provides a comprehensive guide to study design and standardized methods and metrics to determine impacts to birds at existing and future wind farm sites. A stated purpose of the guide is to promote efficient, cost-effective study designs that will produce comparable data and reduce the overall need for some future studies.

These guidelines have been implemented in recent studies at Buffalo Ridge, Minnesota (Johnson et al. 2000c), Wisconsin (Howe and Atwater 1999), Washington (Erickson et al. 1999), Wyoming (Johnson et al. 2000b), Altamont Pass (Thelander 2001), and Tehachapi and San Gorgonio (Anderson pers. comm.). In addition, the monitoring requirement for the repowering of the Altamont Pass WRA (Alameda County 1998) requires monitoring and evaluating the effects of removing old turbines and siting of new turbines to be "generally consistent" with the NWCC's guidelines (Anderson et al. 1999).

A meta-analysis of all the data collected from these standardized studies could determine thresholds of bird use that may result in high risk; previous studies have indicated that certain levels of use result in an unacceptable fatality rate. This information could allow for more effective site evaluation, avoidance of high-risk sites, and reduce the need for post-construction evaluation (Anderson pers. comm.).

To aid bird-risk evaluations, there is a need to define the "level of take" that is acceptable from avian species' interactions with wind turbines—that is, the level of fatalities that can occur without reducing that species' population. The level of assigned risk will vary among species. If threatened or endangered species are affected, incidental take permits can be issued under the federal Endangered Species Act, but "no take" may be the targeted goal. There is no accommodation for take under the Migratory Bird Treaty Act, which applies to a large number of birds, including raptors and passerines that have been killed by collisions wind turbines. To date, the U.S. Fish and Wildlife Service has been somewhat tolerant of existing conditions at WRAs. However, future wind plant approvals—particularly in California where existing avian fatality issues have not been resolved—may be in jeopardy due to enforcement of this act (Anderson pers. comm.).

Research Needs

Although bird fatalities at WRAs in California have been documented since the 1980s, the variations in physical and environmental factors at each development have made it difficult to isolate—and therefore mitigate—those factors that represent the greatest avian fatality risk. Orloff and Flannery (1992, 1996) were the first to document the extent of the problem and present an analysis of factors contributing to collision risk. Later studies were able to further refine risk-assessment surveys following protocols adopted by the NWCC (Anderson et al. 1999). The results of these studies have identified a number of variables that appear to be most associated with high risk, including certain topographical and turbine design features. The information gained to date and pre-construction assessments of bird use have made it possible for some new developments to reduce or avoid risk.

However, existing fatalities at the Altamont Pass WRA continue to be high, and new developments proposed at sites with known high bird use (such as Solano County) warrant further research to develop techniques to reduce risk. Future research should concentrate on completing the analysis needed to understand what factors contribute to risk, developing methods to reduce those risks, and monitoring to determine the effectiveness of those measures.

1. The majority of the Altamont Pass WRA has not been surveyed using the rigorous and standardized techniques adopted by the NWCC. Surveying these areas is important to complete a comprehensive study of the entire Altamont Pass WRA. (see 5.1.2.A and 5.1.2.B)
2. The trend for wind development is the installation of larger, more efficient turbines. The avian collision risks associated with features of these turbines (i.e., rotor-swept area, tip speed, rotations per minute (rpm), rotor blade height, and period of operation) are unknown and need to be evaluated. (see 5.1.2.B and 5.1.2.C)
3. Obtaining scavenging rates is necessary to accurately estimate fatality rates, yet difficult to accomplish, because of site differences in carcass size, location within the WRA, and seasonal and year-to-year variations. Existing methods are costly and time consuming. Further research is needed to determine a standardized methodology that is effective and cost efficient. (see 5.1.2.C and 5.2.2.B)
4. There is a need to develop an economical pre-construction survey protocol to determine risk present at proposed wind sites.(see 5.1.1.D).

5. Avoidance of high-risk sites has resulted in lower fatality rates at newer WRAs and continues to be the optimal solution towards reducing avian fatalities. A significant number of recent studies have incorporated the NWCC guidelines (Anderson et al. 1999) to evaluate risk at WRAs. A meta-analysis of these data sets may provide useful statistics that would help to develop a reliable method for assessing avian risk and avoiding high-risk areas. (see 5.1.1.D)
6. Understanding bird behaviors near turbines may reveal important design considerations that contribute to collision risk. New video technology is being developed that can be used on problem turbines or turbines in high bird use areas and could help reveal the relative importance of design and behavior. (see 5.1.1.F)
7. Methods are needed to identify abundance, species composition, and activity levels of nocturnally active birds to determine the potential risk of a planned WRA. Although radar has been used to quantify abundance of migratory birds, it does not provide data on species composition, nor on resident species such as owls that may be at risk. The feasibility of using additional methods such as night vision scopes and ultraviolet beams should be investigated. (see 5.2.1.B)
8. Following the standardized methods and metrics recommended by NWCC (Anderson et al. 1999), recent studies have produced a rigorous data set to identify risk-contributing characteristics of the Altamont Pass WRA. Their analysis suggests that some of these risk factors can be incorporated into a model that can be used to identify high-risk microsites where turbines should not be placed. (see 5.1.2.A).
9. Effective visual treatments would provide a cost-effective method to reduce risk from turbines determined to cause fatalities. Laboratory and field tests of treatments that make turbine blades more conspicuous to raptors and other birds are needed. (see 5.2.2.A and 5.2.2.C).
10. Habitat modification to reduce prey densities has been discussed as a possible avian risk-reduction technique. There have been some efforts to reduce ground squirrel populations in portions of the Altamont Pass WRA, but no results of the effects on reducing raptor moralities have been published to date. The effects of a widespread control program would have to take into account effects on other wildlife, including protected species that prey on ground squirrel or depend on their burrows for nesting and cover habitat. Widespread use of rodenticides or other measures to remove prey may prove to be controversial and costly. Feasibility of more benign habitat modification measures—such as manipulation of annual grassland grazing practices or conversion to perennial grassland—may be worth studying. (see 5.1.1.E)

4.2 Bat/Wind-Turbine Collisions

Bat fatalities at wind farm sites have not been well documented. Assessments of biological effects of wind energy facilities focused initially on raptors and on birds in general as a result of observations made at Altamont Pass WRA. Bats are not as high profile and have not had the same special status and protection under various state and federal laws as have a large number of bird species. A common assumption is that bats could use echolocation to avoid wind turbines. However, Keeley et al. (2001) indicated that bats might not use echolocation when traveling over long distances in open areas.

At California wind plants, Howell and Didonato (1991) reported finding one dead red bat during a 12-month period, and Orloff and Flannery (1992) reported two dead bats over a 24-month period. Osborn et al. (1996) first reported evidence of more frequent bat fatalities at the Buffalo Ridge WRA in Minnesota, where the number of bats killed (13) was similar to the number of birds killed (12) during a 20-month period. The authors concluded that this level of fatalities was likely not of concern.

Subsequent surveys documented higher numbers of bat fatalities. At the Buffalo Ridge WRA, Johnson et al. (2000c) found 78 bat fatalities in 1998 and 106 in 1999. At Foote Creek Rim, Wyoming, all 45 bat casualties—38 of which were hoary bats (*Lasiurus cinereus*)—were attributed to wind turbine collisions (Johnson et al. 2000a). At the Vansycle Ridge WRA in Oregon, a total of 10 carcasses were found in 1999. Initial reports from a wind farm study by the Wisconsin Public Service Corporation indicate that bat fatalities may be greater than bird fatalities (Keeley et al. 2001).

The majority (85 percent) of the bat fatalities in these studies have been bats in the genus *Lasiurus* and 86 percent of the all bats were found between late August and early October (Keeley 2001). The larger fatality rate of this group of bats could be attributed to several possible factors, including: 1) characteristics that make it more visible during fatality searches than other bats, 2) seasonal behavior, 3) researcher bias, and 4) structural designs of turbines (Keeley pers. comm.). *Lasiurus* bats are typically solitary and likely not the most common bat species in these WRAs, and consequently, it is possible that fatalities at this rate could have a significant impact on populations. The seasonal aspect of these fatalities may be explained by the migration pattern of several species in this genus. They may be more susceptible than other bats because they may be more likely to fly through open areas or at turbine-blade heights, as opposed to other common U.S. bat species that do not travel such great distances. In addition, there is some weak association of fatalities with poor weather events suggesting that bats may have been looking for a place to roost in inclement weather. Bats often use the same migration corridors as birds and this indicates that the San Gorgonio WRA may pose a greater risk to bats than other California WRAs (Keeley pers. comm.), although there are not enough data available to support this assumption. (Any bats protected?)

Outside of the United States, there is little information on the effects of wind-turbines on bats. An Australian study (Hall and Richards 1972) reported 22 Australian free-tailed bat (*Tadarida australis*) collisions with wind turbines. No European studies have reported significant bat fatalities to date, although bats have been observed flying in close proximity to turbine blades (Keeley pers. comm.).

The actual number of fatalities is probably underestimated, because bats are much more difficult to detect than most birds species found during conventional bird fatality searches. Scavenged birds may be easier to detect because scavengers often discard feathers or other body parts, whereas an entire bat—including its fur—could be ingested with few if any traces remaining. In addition, the highest reports of bat fatalities have included tree-dwelling bats that are larger and more colorful than crevice-dwelling bats. It is possible that these smaller bats are injured and seek cover under tufts of grass or other small objects where they are impossible to detect (Keeley pers. comm.).

Keeley et al. (2001) suggested that researchers cannot rely on the same survey methods or equipment that has been employed in bird fatality surveys, and that bat experts need to be consulted regarding preliminary identification of potential threats to bats at specific WRAs and the use of appropriate study designs including carcass recovery methodology. In addition, appropriate utilization studies need to be performed to determine the relative risk of each species. Bat detectors can be used as an indication of use rates and as a means of observing behavior in the vicinity of wind turbines. Keeley (pers. comm.) also suggests that even poorly trained dogs are likely more efficient at performing carcass surveys than humans. Osborn et al. (1996) recommended that wind plants not be constructed near areas with large bat populations, such as hibernacula, where bats foraging before and after hibernation or migration could be in close proximity with wind turbines.

Research Needs

Little study has been done on the impacts of WRAs on bats. Most reports of bat fatalities have been incidental to avian fatality surveys.

1. Researchers need to develop a methodology that implements nighttime surveys using bat detectors and other species-specific equipment, to evaluate proposed WRAs where special-status bat species are suspected of being at risk. (see 5.2.1.B)

4.3 Avian Electrocution and Wire Collision Impacts in Wind Resource Areas

4.3.1 Electrocution Impacts

Distribution lines at California WRAs can electrocute birds when raptors simultaneously touch two or more wires, or touch one wire and a ground, with their wings or other parts of their bodies. Olendorff et al. (1981) reported that raptors are the group most often reported in electrocution incidents. Sites such as the Altamont Pass WRA place birds at greater risk because of the abundance of prey and the perching area provided by power poles (Colson 1995b). Olendorff et al. (1981) suggested that rain-soaked birds are more likely to become electrocuted when they perch on a power pole. In some WRAs, such as Altamont Pass, seasonal fog and rain coupled with wind may contribute to higher electrocution risks.

In 1984–1988, the California Energy Commission reported 36 raptor electrocutions out of 108 total raptor fatalities (33 percent) in its examination of wind energy operations at Altamont Pass, Tehachapi Pass, and San Gorgonio Pass. Early studies at the Altamont

Pass WRA indicated that electrocution was the second-most common cause of avian fatalities, after wind turbine collisions. Orloff and Flannery (1992) attributed 7.7 percent of the avian fatalities and 25 percent of the golden eagle fatalities to electrocution. At total of 92 raptor electrocution fatalities was reported to Alameda County by operators in the Altamont Pass WRA between 1985 and 1997 (Alameda County 1998). However, no bird electrocutions were found in a fatality survey at the Tehachapi WRA (Orloff 1992). A four-year study conducted at the Montezuma Hills WRA, which included pre- and post-construction evaluations of the site, reported no bird electrocutions (Howell and Noone 1992).

In the 1980s, the wind industry initiated attempts to reduce raptor electrocutions at the Altamont Pass WRA by incorporating mitigation recommended by Olendorff et al. (1981). Mitigation measures included insulating power poles and associated hardware and installing perch guards designed to deter birds from perching. However, Colson (1995b) observed that in the absence of trees and other natural perches, raptors were still using power poles with perch guards, but were now occupying more unusual and dangerous places such as riser switches, neutral ground wire, and post insulators. He therefore recommended the installation of elevated "T" perches and other devices designed to accommodate raptors safely on power poles.

This retrofitting has occurred throughout much of the Altamont Pass WRA and appears to have reduced bird electrocutions significantly (Colson pers. comm.). Recent fatality surveys at the Altamont Pass WRA indicate that although some bird electrocutions have occurred, they are at such a level that they represent no greater risk to birds than any other common electrical distribution structures in California (Thelander pers. comm.). Hunt (2002) reported 12 golden eagle fatalities from electrocution during 88 months of study of the region within 40 km of the Altamont Pass WRA. None of the electrocutions, however, occurred within the WRA.

There have been fewer electrocutions reported at WRAs other than the Altamont in California, and throughout the United States and Europe. This is likely due to the absence of a high density of foraging raptors and, in some cases, drier, less hazardous conditions at WRAs such as San Gorgonio and Tehachapi. In addition, most new wind farms have fewer larger turbines reducing the required amount of distribution lines and some have placed their lines underground or installed raptor safe poles or perch guards (Strickland pers. comm.).

4.3.2 Wire Collision Impacts

Few studies have looked at the impacts of bird collisions with power lines and guy-wired wind turbines and meteorological towers within WRAs. Orloff and Flannery (1992) reported that the number of non-raptor fatalities attributable to collisions with electrical and guy wires were higher than the number attributable to wind-turbine blade collisions. Eleven percent of all the fatalities in their study were a result of collisions with electrical and guy wires. Orloff and Flannery (1992) compared five different turbine types, and the two with guy wires (i.e., vertical axis and guyed pipe) had the lowest fatality rates. However, these types of turbines also had the lowest operational time of the turbine types surveyed. No other studies have compared guyed turbines with other turbine types (Erickson et al. 2001). Orloff and Flannery also recorded no avian fatalities at 48 meteorological towers with guy wires. In a one-year survey, however, Johnson et al. (2000a) recorded 16 bird fatalities (primarily passerines) attributable to collisions with the five meteorological towers at the Foote Creek Rim WRA in Wyoming. This fatality rate was higher than that which occurred at the wind turbines on this site. In response to these data, SeaWest, a wind-energy developer, is planning to minimize the use of meteorological towers in future expansion of the WRA (Strickland et al. 2001) and several recent or proposed projects in the western United States use meteorological towers without guy wires (Wally Erickson pers. comm., Joan Stewart pers. comm.).

Although many guyed communication towers have been considered a significant source of avian fatalities, there are few reports of fatalities at structures less than 500 feet in height (Erickson et al. 2001). FAA-required lighting of towers over 200 feet appears to play a role in fatalities at communication towers where low visibility conditions attract birds to the lights. They become disoriented, circle, and collide with guy wires (Ugoretz 2001). Wind turbines are generally less than 350 feet high, and most do not have guy wires (Erickson et al. 2001).

Research Needs

It appears that an aggressive effort to mitigate electrocution and wire collision at wind facilities has reduced risk at existing facilities. At new facilities, with the use of bird safe distribution poles, underground transmission lines and the elimination of guyed wind turbines and meteorological towers, significant avian wire collision and electrocution fatality risk can be avoided. While it is recommended that wind industry monitor, and when necessary mitigate this impact, no research is necessary in this area at this time.

5. Goals

The goal of the PIEREA research on avian interactions with wind turbine is to help California benefit from reduced impacts on birds and bats from wind turbines in the State, and to facilitate the development of environmentally responsible wind power in the State.

The achievement of these goals depend on the ability of researchers and wind turbine developers to assess risk to birds and bats from these structures and this equipment, and to develop effective mitigation. The following research goals are designed to contribute to better understanding and successfully reducing or eliminating avian fatality risk.

Appropriate evaluation and avoidance of high-risk sites is recognized as the single most important means of reducing risk for proposed sites, and research is proposed below that would further develop this methodology.

Research should be conducted where specific risk factors can be determined and risk-reduction measures developed, and the Altamont Pass WRA is an optimal area to conduct much of this research. The high abundance of raptors in the Altamont WRA, the relatively high avian fatality rate in the area, and the large number of turbines at the site all present the best opportunity for continued research that will result in a robust statistical evaluation of risk factors and potential reduction methods.

Below is a prioritized list of research, divided into short-, medium- and long-term time frames. Although there is overlap with other goals, short-term research projects are aimed primarily at continuing to define the most important risk factors. Many medium-term research goals are aimed at developing and evaluating risk reduction measures. Finally, long-term research goals involve monitoring changes due to the development of risk-reducing measures or to the development of new technologies (e.g., larger, more efficient turbines), wind farm sites, or configurations.

The PIEREA program recognizes that much work is currently under way in these areas and seeks to draw from, build upon, and broaden the focus of those efforts. Whenever possible, PIEREA will identify existing efforts and form partnerships to leverage resources.

5.1 Short-term Objectives[1]

5.1.1 Crosscutting

A. **Update Wind Turbine Effects Bibliography ($30K)**

Activities needed: (1) Update *Effects of Wind Energy Development: An Annotated Bibliography,* the original annotated bibliography produced for the California Energy Commission that compiled available literature on the effects of wind energy on wildlife from 1970 to 1995. Collect, annotate, and archive all available literature from 1996 to present.

Critical Factors for Success:

- Access to the gray literature (such as agency reports) that may be out of print or difficult to find will be important for developing a complete bibliography.
- Some wind developers have performed their own avian collision research, but may be reluctant to provide wider access to their reports. It is crucial that these valuable studies be available to researchers addressing the topics outlined in this roadmap.

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[1] S*hort-term* refers to a 1–3 year time frame; *mid-term* to 3–10 years; and *long-term* to 10–20 years. The activities specified in the roadmap are projected to begin sometime within the designated time frames, and the duration of actual projects may be less than the entire term specified.

5.1.2 Avian/Wind Turbine Interactions

A. **Continue Studies to Assess Turbine/Site Characteristics Associated with Fatalities ($200K)**

Activities needed: (1) Continue the current funding of studies in the Altamont WRA that are evaluating turbine and micro-site characteristics that may be associated with higher avian fatality rates (e.g., tip speed, rotor diameter, turbine position and spacing, turbine type and height, and micro-topography). These studies are currently being conducted by BioResource Consultants. (2) Expand the study area to include larger sample sizes of different turbine types.

Critical Factors for Success:

- see 5.1.2.A
-

B. **Develop a Risk Assessment Model ($40K)**

Activities needed: (1) Develop a model that evaluates the micro-site characteristics that increase the risk of avian fatalities. A portion of this study is a work in process and is being conducted at the Altamont WRA by BioResource Consultants. A mid- term goal will be an evaluation of the risk model that is developed. (2) Use the model to evaluate site plans for newer turbines and remove problem turbines.

Critical Factors for Success:

- Most important is the cooperation from wind energy companies. To study a representative sample of all the risk-contributing variables in the Altamont Pass WRA, it is important to have access to the entire site, which has not been the case throughout its history. Wind energy companies control the majority of the turbines, and have not allowed access to their wind turbines for research purposes. Consequently, past studies have been limited in their scope and conclusions. In addition, if risk-reduction methods are to be tested, wind energy companies must be willing to permit—and possibly assist with development and funding of modifications to—turbines, site, or spatial configurations.
- Cooperation from oversite agencies will be required, because these agencies require wind energy companies to monitor the significant changes that they will be implementing through their proposed repowering effort. This monitoring effort is compatible with many of the research goals in this document, and cooperation from oversight agencies such as Alameda and Contra Costa Counties will be essential to enforce mitigation requirements and encourage cooperation from wind energy companies.
- Application of appropriate research methodologies is essential for successful research. Any research proposal should be based on the standardized methods outlined by the NWCC and should be subject to review by members of the NWCC Avian Subcommittee or individuals familiar with the design protocols.

- For the results of future research projects to receive acceptance by a wider audience and within the scientific community as a whole, researchers should be required to publish their results as part of their scope of work. There few research results about California-based research on bird interactions with wind turbines that have been published in peer-reviewed scientific journals. Most of the results relied upon for these assessment appear in the form of project reports, and the quality of the results vary considerably.

C. **Conduct Wind Resource Area Repowering Studies ($450K)**

Activities needed: (1) Evaluate avian risk effects of planned repowering or new facility installations at higher-risk wind resource areas such as Altamont and Solano WRA's. (2) Field-test the hypothesis that the replacement of old wind turbines with newer larger capacity wind turbines will significantly reduce avian fatalities. (3) Evaluate the potential avian fatality risk of night navigation lighting on newer model, tall turbines proposed for installation at the Altamont, Solano and other California WRA's. Determine if any species-specific or larger multi-species migratory populations are at risk. (4) Evaluate the relative risk of different types of lighting (e.g. strobe vs. constant, white vs. red).

Critical Factors for Success:

- See 5.1.2.A.
- The mitigation plan for the planned Altamont Pass Repowering project requires oversight by an avian Technical Advisory Committee (TAC) formed jointly by Alameda and Contra Cost Counties. Mitigation for new facilities at the Solano WRA also requires some level of post-construction risk assessment. Research and funding goals of the TAC and other mitigation oversight groups will overlap with the PIEREA program, and leveraging and planning efforts should be coordinated to assure effective use of funds.

D. **Identify Risks of Potential Wind Resource Areas ($100K)**

Activities needed: (1) Perform a meta-analysis of U.S wind turbine studies that have employed the standardized and comparable NWCC methodology to determine thresholds of avian density, site characteristics, and other variables that allows a better understanding of the data that have been collected. This analysis could also be used to develop a methodology for preconstruction assessments of levels of avian risk.

Critical Factors for Success:

- Access to all data from all relevant studies will be necessary. Some of this information may be proprietary and difficult to obtain.

E. **Conduct a Study of Habitat Manipulation Feasibility ($50K)**

Activities needed: (1) Determine the feasibility and mechanisms of manipulating grazed annual grassland to discourage prey abundance in areas that present a high avian fatality risk. Evaluate compatibility with fire prevention, turbine maintenance practices, water quality and other management practices. Evaluate the potential to affect other sensitive species in the area.

Critical Factors for Success:

- Obtain feedback from landowners and wind energy companies on the feasibility of altering land-management activities. These stakeholders may have concerns about the consequences of habitat manipulation, such as increased fire danger, impacts on water quality (e.g., Los Vaqueros Reservoir), and loss of revenue.

F. **Conduct Video Monitoring at High-Risk Wind Turbines ($150K)**

Activities needed: (1) Place video monitoring equipment at wind turbine sites of known risk to birds. (2) Monitor recordings to observe bird fatalities or identify behaviors that would indicate causes of collisions with wind turbines. (3) Evaluate the behavior of birds at different wind turbine configurations and site characteristics.

Critical Factors for Success:

- See 5.1.2.A
- Access to high-risk turbines, provided by landowners and wind developers, will be critical.

5.1.3 Avian Electrocution and Wire Collision Impacts in Wind Resource Areas

A. No research specific to wind resource areas is needed currently. However, research areas addressed in PIEREA's roadmaps, on avian collision with power lines and avian power line electrocution may have some relevant applications to wind facilities.

Activities needed: (1) None at this time.

Critical Factors for Success:

- Not applicable.

Table 4. Short-term Budget

Objective	Projected Cost ($000)
5.1.1.A Update Wind Turbine Effects Bibliography	30
5.1.2.A Continue Studies to Assess Turbine/Site Characteristics Associated with Fatalities	200
5.1.2.B Develop a Risk Assessment Model	40
5.1.2.C Conduct Resource Area Repowering Studies	450*
5.1.2.D Identify Risks of Potential Wind Resource Areas	100
5.1.2.E Conduct a Study of Habitat Manipulation Feasibility	50
5.1.2.F Conduct Video Monitoring at High-Risk Wind Turbines	150
Total	**1020**

Note: An asterisk (*) indicates a high probability that the work will be leveraged with other ongoing efforts. The figure given is the California Energy Commission's projected expenditure.

5.2 Mid-term Objectives

5.2.1 Crosscutting

A. **Conduct Eagle Nesting Surveys to Evaluate the Status of Golden Eagle Population ($100K)**

Activities needed: (1) Sample each known breeding site every two years over a period of six years to determine level of occupation, including presence and age class of breeding pairs. Monitoring annual breeding success is a likely indicator of continued stability; there is a limited number of breeding eagles in the total population and a decline in this number would indicate a potential decline in the population.

B. **Develop Nocturnal Survey Methods for Birds and Bats ($20K)**

Activities needed: If new wind energy sites in the state are proposed with the potential for risk to bats and nocturnal bird migrants: (1) Develop a feasibility study to evaluate the potential to use several devices (e.g., night vision scopes, ultraviolet beams, and bat detectors) to monitor nocturnal bird and bat activities in wind resource areas. (2) Determine whether the use of such methods would reduce study costs, compared to conventional radar detection methods. (3) Determine if these methods could be used for pre-construction site surveys.

5.2.2 Avian/Wind Turbine Interactions

A. **Conduct Field Studies on Turbine Blade Visibility ($150K)**

Activities needed: (1) Paint a representative sample of turbines with a motion-smear reducing pattern. Perform field studies of both treated and control turbines, and analyze data to determine if there are significant differences in bird fatality risk.

B. **Develop Improved Techniques for Determining Scavenging Rates ($50K)**

Activities needed: (1) Develop field tests to improve the methodology used to determine scavenging rates during avian fatality searches. To evaluate bird fatality rates and fatality risk, scavenging rates must be determined at each site, which is a difficult process. Improved methods will yield more accurate data for impact evaluations of wind energy on birds and other wildlife.

C. **Evaluate the Use of Risk-Reducing Devices ($100K)**

Activities needed: (1) Determine availability and feasibility of use of bird deterrent devices such as visual and audio warning systems. (2) Investigate the use of such devices on other human-made structures that pose a risk to bird fatality, such as communications towers, buildings, and meteorological towers.

D. **Evaluate the potential risk of off shore wind farm development (unknown)**

Activities needed: (1) Determine where potential offshore windfarms are planned in the United States and identify design parameters critical to evaluate risk such as density and spatial distribution of turbines, and wind turbine design (2) Determine species that may be at risk, and evaluate resident and migratory movement patterns. 3) Determine pre-siting risk assessment techniques. 4) Investigate modifications to existing standardize methods that would be applied to the offshore conditions

5.3 Long-term Objectives

5.3.1 Crosscutting

A. **Continue Monitoring (No $ estimate possible.)**

Activities needed: (1) Continue to monitor variables that have an effect on avian and bat fatality risk. This project would address specific techniques and designs intended to reduce risk, in addition to new wind turbines and resource areas that become developed in the 10–20 year time frame.

6. Leveraging R&D Investments

Stakeholders include the various wind energy companies who currently operate in the Altamont Pass WRA and provide access for research. They would possibly be implementing changes to wind turbine and wind resource area designs, either through their own desire to upgrade their facilities, through required actions by oversight agencies, or through modifications suggested by risk-reduction researchers.

The Alameda County and Contra Costa County Planning Departments are the lead agencies responsible for permitting/licensing under CEQA present and future repowering efforts at the Altamont Pass WRA. The Alameda County Repowering Scientific Task Group is responsible for oversight of the long-term monitoring efforts required for implementation of the proposed Altamont Pass WRA repowering effort. Studies funded by PIEREA that would determine avian fatality risk of the Altamont Pass repowering effort would likely be directly linked to monitoring studies supervised by the Task Group. Landowners that lease their property to wind energy companies would provide access to researchers. Their leases could be indirectly impacted by changes that result from research. Nearby residents may have concerns about visual and auditory changes in turbines, access, or other issues that may directly affect them.

Other stakeholders that are involved in wind energy research, development, or funding include the National Renewable Energy Laboratory, National Wind Coordinating Committee, American Wind Energy Association, the Electric Power Research Institute, and Pacific Gas and Electric Company. The U.S. Fish and Wildlife Service and California Department of Fish and Game have statutory jurisdiction over avian fatalities caused by wind-turbines. Local and Regional environmental organizations such as the Sierra Club and Audubon Society also have an interest in protecting birds from human-caused fatalities.

6.1 Methods of Leveraging

It is hoped that much of the work identified in this roadmap would be collaborative with other entities; PIEREA would either cofund projects by other entities or use outside funds to support PIEREA efforts. Historically, public/private collaboration on this issue has been limited. However, the current repowering efforts at the Altamont Pass WRA, recent spate of new wind turbine technologies, lower wind turbine production costs, and renewed interest and support for the burgeoning wind industry are all converging to create a particularly productive window for this type of collaboration.

Specifically, this roadmap seeks to:

- provide PIER funds for cofunding existing or planned work on this topic by the wind industry.

- solicit funds from National Renewable Energy Laboratory (NREL) to build upon their past efforts, or to co-design new projects at the Energy Commission.

PIEREA hopes to be able to expand its collaborative opportunities considerably.

6.2 Opportunities

No co-sponsored efforts are already under way at this time. Potentially, co-sponsorship opportunities are possible with the National Wind Coordinating Committee, NREL, Alameda and Contra Costa counties, and members of the wind industry. Each of these organizations is interested in addressing avian-wind collision issues.

Some critics contend that a lack of cooperative research on this issue is attributable to a lack of regulatory enforcement. If true, greater regulatory enforcement of existing avian protections by the U.S. Fish and Wildlife Service and the California Department of Fish and Game would spur greater cooperation and research on this issue.

No specific collaborative opportunities have been identified at this time.

7. Areas Not Addressed by This Roadmap

No areas of this topic were deliberately avoided for this roadmap.

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9. Personal Communications

9.1 Interview List

The following individuals are considered experts on issues of bird or bat interactions with wind turbines, and were selected for interviews for assistance in developing this roadmap. Their input was invaluable in assisting with identification of problem areas and development of research priorities. Below is a list of individuals contacted for interviews and the date interviewed. It was not possible to contact some individuals, some did not respond or declined the interview as indicated.

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- Bragg, Charles. National Audubon Society, Pacific Palisades, California June 29, 2001.
- Carlton, Richard. Electric Power Institute, Palo Alto, California. July 2, 2001.
- Colson, Ed. Pacific Gas and Electric Company, San Ramon, California. June 29, 2001.
- Crowder, Michael. Department of Forestry and Natural Resources, Purdue University
- West Lafayette, Indiana. Unable to contact.
- Estep, Jim. Jones & Stokes, Sacramento, California. September 9, 2001.
- Harness, Richard. EDM International, Fort Collins, Colorado. July 5, 2001.
- Hodos, William. University of Maryland, College Park, Maryland. July 25, 2001.
- Hunt, Grainger. Predatory Bird Research Group, U C Santa Cruz, California. July 6, 2001
- Keeley, Brian. Bat Conservation International, Austin. Texas. July 2, 2001.
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- Morrison, Michael. White Mountains Research Station, California. No response.

- Orloff, Sue. Ibis Environmental Services. San Raphael, California. August 2, 2001.

- Pearson, Dan. Southern California Edison, Rosemead, California. No response.

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- Sinclair, Karin. National Renewable Energy Lab, Golden, Colorado. July 20, 2001.

- Spiegel, Linda. California Energy Commission . Numerous, 2001/02.

- Stewart, Joan. FPL Energy, Inc., Livermore, California. July 12, 2001.

- Strickland, Dale. Western Ecosystems Technology Inc., Cheyenne, Wyoming. June 28, 2001.

- Thelander, Carl. BioResource Consultants, Ojai, California. June 28, 2001.

- Thresher, Robert. National Renewable Energy Lab, Golden, Colorado. July 6, 2001

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- Anderson, Richard. California Energy Commission, Sacramento, California. Personal Communication August 21, 2001.

- Colson, Ed. Pacific Gas and Electric Company, San Ramon, California. Personal Communication June 29, 2001.

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- Keeley, Brian. Bat Conservation International, Austin, Texas. Personal Communication July 2, 2001.

- Johnson, Gregory. Western Ecosystems Technology Inc., Cheyenne, Wyoming. Personal Communication April 28, 2002.

- Orloff, Sue. Ibis Environmental Services, San Rafael, California. Personal Communication August 2, 2001.
- Sinclair, Karin. National Renewable Energy Laboratory, Golden, Colorado. Personal Communication July 20, 2001.
- Stewart, Joan. FPL Energy, Inc., Livermore, California. Personal Communication October 15, 2001.
- Strickland, Dale. Western Ecosystems Technology Inc., Cheyenne, Wyoming. Personal Communication June 28, 2001.
- Thelander, Carl. BioResource Consultants, Ojai, California. Personal Communication June 28, 2001.

Appendix A

Current Status of Programs

This section outlines those efforts that most closely address the avian collision issue and its impact on California.

It is important to note that current research in this area is sparse, and that much of the research that is addressing avian/wind turbine issues is being conducted by private entities such as wind turbine developers and owners. Because the results of this private research is proprietary, this roadmap is unable to include it here; therefore, the listing below is incomplete. This Appendix focuses on efforts by public entities.

Current Status: California

California Energy Commission

- In 1998, PIEREA funded the continuation of a 4-year project conducted by the University of Santa Cruz. Called "Golden Eagles in a Perilous Landscape: Tracking the Effects of Mitigation for Energy Based Mortality". This 7-year study examined the dynamic between wind turbines and golden eagles in the Altamont Pass WRA. The study concluded that in the Altamont Pass Wind Resource Area (WRA), wind turbine blades kill an estimated 40 – 60 golden eagles per year and represent a significant mortality source. Due to their frequent occurrence in the WRA and to their tendency to hunt for live prey while in flight, subadults (ages 1-3) and nonbreeding adults are more vulnerable to turbine strikes. Circumstantial evidence suggests that areas containing Kenetech 56-100 turbines on an 18.3-meter lattice tower present the greatest hazard. However, it is not clear if the turbines themselves or extraneous environmental factors associated with the location are causing the fatalities. The regional eagle population does not appear to be declining and nesting territories in the vicinity of the WRA have remained occupied. However, concern remains for the high mortality rate of eagles from turbines, particularly because they are the future breeding population and because impacts from land use changes in the vicinity of the WRA is resulting in a high degree of emigration..
- In 2002, PIEREA began a project in the Altamont Pass WRA with BioResource Consultants to (1) identify biological and physical features that contribute to collision risk, (2) develop a model to identify and reduce collision risk, and (3) determine the effect of repowering with larger turbines.

Current Status: Regional and National

National Renewable Energy Laboratory

- The National Renewable Energy Laboratory (NREL) has funded projects to address the avian/wind turbine issue since 1994. In 1994, NREL and the U.S. Department of Energy began hosting a series of National Avian-Wind Power Planning Meetings to discuss such research. The National Renewable Energy Laboratory also participates in the national Wind Coordinating Committee's (NWCC's) Avian Subcommittee. NREL has also supported a number of studies including:
  1. Research in the Altamont Pass WRA to explore factors responsible for bird/turbine interactions and bird deaths and to develop recommendations for reducing bird/turbine interactions.
  2. Two studies cofunded by CEC at the Tehachapi Pass and San Gorgonio Pass WRA's to investigate the influence of tower type and size on bird use behavior , and mortality.
  3. A preconstruction site study at Ponnegquin Wind Far on Colorado cofunded by Xcel Energy to develop baseline information on avian use and relative abundance.
  4. An evaluation of impacts of wind turbine development and three aspects of avian behavior – night migration of songbirds, daytime migration of hawks, and breeding – at Green Mountain Power's wind turbine development in Searsburg, Vermont.
  5. A preconstruction study conducted at the Conservation and Renewable Energy System's (CARES) proposed wind facility site near Goldendale, Washington. The purpose of this study was to study avian use and abundance, monitor scavenging rates and develop recommendations for reduce bird/turbine interactions.
  6. Research to determine if UV coated turbines blades will reduce bird fatalities at Foote Creek Rim WRA in Wyoming.
  7. Preconstruction research at Norris Hill WRA in Montana to determine bird use of the area including migratory (nighttime and daytime) and breeding and local birds.

Some preliminary results of these studies have been reported and cited in this document where relevant. Policy shifts in the new administration have influenced the availability of funding and it appears that NREL will be provided fewer funds for bird/turbine interaction studies in the near future (Sinclair, pers. comm.).

National Wind Coordinating Committee

- The NWCC, is a consensus-based collaborative of electric utilities and support organizations, state legislatures, state utility commissions, consumer advocacy offices, wind equipment suppliers and developers, green power marketers, environmental organizations, agriculture and economic development organizations, and state and federal agencies. In December 1999, the group published *Studying Wind Energy/Bird Interactions: A Guidance Document.* The publication established guidelines methods and metrics for determining and monitoring potential impacts on birds at existing and proposed wind energy sites. Use of these guidelines is becoming more commonplace, and will enable researchers to better compare data from different studies and WRAs.

Bat Research

- A number of bat-wind turbine interaction studies with various funding sources are being conducted in the United States. Most studies are focusing on surveys to determine of level of bat use, species composition and fatalities (Keeley pers. comm., Greg Johnson pers. comm.). The following is a list of some of the current studies and their objectives:

    1. At Buffalo Ridge WRA, Minnesota a study to determine fatality rates and use funded by the EPRI. Use of bat detectors and mist nets to determine species composition and use of area. Study includes determination of bat carcass detection rates as well as scavenging rates.
    2. At a Wisconsin Public Service (WPS) facility, a study to determine level of use and fatalities. This study is funded by the WPS
    3. At SeaWest WRA in Wyoming, a study to determine level of use and fatalities. This study has multiple funding sources including EPRI and BLM.
    4. At the Buffalo Mountain WRA in Tennessee, fatality surveys are being conducted and funded by the Tennessee Valley Authority.