CALIFORNIA
ENERGY
COMMISSION

ENERGY RELATED ENVIRONMENTAL RESEARCH

A Roadmap for PIER Research on Avian Collisions with Power Lines in California

COMMISSION STAFF REPORT

December 2002
P500-02-071F

Gray Davis, *Governor*

CALIFORNIA ENERGY COMMISSION

Prepared By:
Kevin Hunting
Wildlife Consultant

Prepared For:
California Energy Commission
Energy Related Environmental Research

Linda Spiegel
Program Manager

Kelly Birkinshaw
Team Lead

Terry Surles
Deputy Director
Technology Systems Division

Steve Larson
Executive Director

Acknowledgements

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

- Dick Anderson/California Energy Commission (CEC)
- Michael Avery/U. S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS), National Wildlife Research Center (NWRC)
- John Bridges/Western Area Power Administration (WAPA)
- Sheila Byrne/Pacific Gas & Electric (PG&E)
- Richard Carlton/Electric Power Research Institute (EPRI)
- Ed Colson/Colson & Associates
- Mark Dedon/Pacific Gas & Electric (PG&E)
- Katie Fehring/Point Reyes Bird Observatory (PRBO)
- Monte Garrett/PacifiCorp
- Richard Harness/EDM International, Inc.
- Albert Manville/U.S Fish and Wildlife Service (USFWS)
- Daniel Pearson/Southern California Edison (SCE) (APLIC)
- Linda Spiegel/California Energy Commission (CEC)
- Dale Strickland/Western EcoSystems Technology, Inc. (WEST)
- Carl Thelander/BioResource Consultants
- Mark Wilson/Consultant
- Marcus Yee/California Energy Commission (CEC)

Contents

Tables

Executive Summary

Power lines are a seemingly ubiquitous part of the modern landscape. Williams and Colson (1989) estimated that there were approximately 588,447 kilometers (km) (365,644 miles) of power lines in the United States as of 1977; and as of 2000, the Edison Electric Institute (2001) estimated that there were 800,000 km (500,000 miles) of transmission lines alone. While power transmission and distribution systems provide electricity to millions of people, they pose a potential collision threat to birds in flight. Recent estimates place collision fatalities at tens of thousands to 174 million birds annually and this magnitude of fatalities is supported by mortality rates reported in the literature.

The extent of avian power line collision fatalities in California is unknown. Fatalities from collisions with transmission lines can be biologically significant when they directly or indirectly cause large or sustained population declines or result in chronic population-level impacts. California's Central Valley falls within the Pacific Flyway and supports more than 60 percent of the state's total duck and goose populations and about 25 percent of the nations waterfowl population. On average, the Central Valley seasonally hosts 100 percent of the world population of both the Aleutian Canada geese and Pacific tule geese; 80 percent of the nation's population of Ross geese and cackling Canada geese; and, 67 percent of the nation's population of tundra swans and pacific white fronted geese. In 2001, about 5.5 million waterfowl used the Central Valley during winter. There are about 5,000 miles of transmission lines that transect Wildlife Refuges, state Wildlife Areas, and other natural resource conservation lands in California's Central Valley alone. Considering the vast network of lines and the high degree of bird use and habitat diversity throughout the state, it is likely that fatalities range in the hundreds of thousands.

Almost all resident and migratory birds are protected under the Migratory Bird Treaty Act and other state and federal laws making collision fatalities a potentially significant legal issue. However, currently, there are no legal requirements for electric utility companies to report fatalities, and they are reluctant to do so because of the specter of legal repercussions.

Published research and reports have identified causes of avian collision with power lines and report mitigation strategies and technologies for detecting and reducing collisions. However, without a regulatory reporting framework and process for assuring ready access to this information, it is difficult for researchers to determine the extent of the problem, identify problem lines and regions, develop effective, site-specific mitigation strategies and technologies, and evaluate mitigation measures after they have been implemented. Undoubtedly, avian collision fatalities will increase with heightened demand for new power lines from new generation systems and land developments in California; therefore, it is imperative that this problem be addressed.

The Public Interest Energy Research Environmental Area (PIEREA) has identified research that could significantly reduce the number of avian collisions with power lines. First, researchers must develop or identify a standardized method for estimating collision mortality from dead bird searches and remote-sensing technologies. This standardization will enable researchers to compare study results and improve the reliability and accuracy of both data collection and research conclusions. Second, research should be focused on determining the species-specific effectiveness of mitigation devices, their durability under varying field conditions, and their application on various transmission line designs in California. This type of research will help ensure installation of the most-effective devices in the most-affected areas. Third, continued rigorous testing and documentation of the effectiveness of remote collision detection devices is essential to allow detection of collisions in areas where firsthand observation is difficult or impossible. Fourth, researcher efforts should be emphasized in wildlife habitats known to support concentrated avian use to aid in further refining collision risk factors. Finally, it is important for industry, regulatory, and academic stakeholders to work together to develop an avian collision reporting requirement. To be effective, this reporting requirement should be developed through a consensus building process, and would embody the needs of all stakeholders—enabling researchers to collect and interpret a wider variety of data that would allow improvement of mitigation efforts in cooperation with transmission line owners and operators.

The successful completion of the activities noted in the Goals section will help the State reduce avian power line collision fatalities. California's rich avifauna is a public resource used and enjoyed by millions of residents. Balancing the clear need for electrical power transmission and distribution with stewardship of a valuable natural resource should be the goal of research programs in this focus area. Finding solutions to this problem will also ultimately reduce industry exposure to legal actions and potential negative public perceptions and improve compliance with State and federal laws.

The products from this suggested research will enable electric utilities and electric power industry representatives to mitigate the effects of power lines on avian populations and comply with regulations affecting birds. Providing tools to help identify problem areas will also considerably reduce mitigation and remediation costs. Consistent and accessible data acquired through this research will help state and federal regulators develop effective and appropriate regulations that will both protect bird populations and ensure the reliable transmission of electricity to California citizens. Lastly, this work will help researchers better understand the causes of avian collisions with power lines, which will enable them to develop the most effective mitigation strategies and technologies.

The PIEREA Avian Collision Roadmap identifies short-term (1-3 years), mid-term (3–10 year), and long-term (10–20 year) goals designed to build on information and techniques resulting from research from preceding goals. In the short-term (1–3 years) this roadmap recommends addressing the following objectives:

Objective	Projected Cost ($000)
• Develop or identify a standardized method for estimating collision mortality from dead bird searches and remote sensing technologies.	50
• Determine the species-specific effectiveness of devices, their durability under varying field conditions, and their application on various transmission line designs in California.	750*
• Test and document the effectiveness of remote collision detection devices.	300*
• Determine collision risk in wildlife habitats known to support concentrated avian use.	500
• Determine the factors necessary to develop an avian collision reporting requirement	50
Total Short-term Cost	**1650**

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.

Roadmap Organization

This roadmap is intended to communicate to an audience that is technically acquainted with the issue. 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 avian collision work. *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 to avian collision research that the proposed activities do not address. *Appendix A: PIER Roadmap Questionnaire and List of Recipients* lists the questions developed for an advisory team assembled to review avian collision issues and indicates questionnaire recipients. *Appendix B: Current Status of Programs* offers an overview of work being done to address avian collision issues. *Appendix C: Short-term Avian Collision Roadmap Research Goal Summary* provides a detailed synopsis of PIEREA's suggested work.

1. Issue Statement

There is a need for methods and tools to determine the statewide extent of, and to reduce and/or prevent, avian collisions with power lines and utility structures.

2. Public Interest Vision

The primary mission of the California Energy Commission's Public Interest Energy Research (PIER) program is to conduct research that helps deliver "…environmentally sound, safe, reliable, and affordable electricity…" to California citizens. PIER's Environmental Area PIEREA mission is "to develop cost-effective approaches to evaluating and resolving environmental effects of energy production, delivery, and use in California, and explore how new electricity applications and products can solve environmental problems." The purpose of this *Roadmap for PIER Research on Avian Collision with Power Lines in California* is to summarize current research, identify research needs on this issue, and ultimately support the development and application of methods and technologies for reducing and resolving negative impacts from avian collisions with power lines.

The Avian Collision roadmap focuses on this issue because in California, avian fatalities from collisions with transmission lines and other utility structure conductors can affect local and regional bird populations, in some cases resulting in significant population declines, and the scope and magnitude in most geographic areas remains largely unknown. Research on this issue is almost non-existent in California despite the potential for widespread and significant impacts.

As mentioned above, the extent of avian fatalities from collisions in California is unknown, but considering the vast network of lines, the avian diversity (over 600 bird species in resident or seasonal roles in California), and complex matrix of wildlife habitats throughout the state, it is likely that fatalities range in the hundreds of thousands annually. Utilities are reluctant to report fatalities because of the specter of legal repercussions, and there are currently no legal requirements for them to do so. Undoubtedly, avian collisions will increase with heightened demand for new lines from new generation systems and land developments, therefore, it is increasingly important that this problem be addressed.

As described in the roadmap, researchers have documented fatalities worldwide under a wide variety of biological and physical conditions. Despite acknowledgement of the lack of consistent research methods and limited geographic scope of published studies and the clear identification of the problem, there has been a lack of focus on the issue. Currently there is a renewed interest in avian fatalities from interactions with power lines and utility structures partly due to the realization that in the past, the problem was actively identified and measures to reduce collision potential developed but implementation either has not occurred or has been largely ineffective. Progress has been made in the last decade to understand causes of collision risk; however, many of the solutions developed to address those causes are still unproven or have proven ineffective. For example, marking devices designed to increase line visibility are in use, but the efficacy of each design has not been documented and remains poorly understood. Moreover, identifying and subsequently mitigating problem lines can be expensive and, in some cases, is considered by industry to be cost prohibitive.

Research is needed in a number of areas to gain a more complete understanding of the scope and magnitude of the problem and develop more effective, area- and species-specific mitigation and remediation measures. First, research should focus on identification and development of standardized methods for estimating collision mortality from dead bird searches and remote-sensing technologies. Standardization will allow meaningful comparison of study results and aid in identification of particularly hazardous designs or areas. Second, research should be directed towards determining the species-specific effectiveness of mitigation devices, their durability under varying field conditions, and their application on various transmission line designs in California. This work would refine mitigation and remediation techniques matching the most effective devices to line segments exhibiting characteristics best corrected by a particular device. Third, research should be supported to test and document the effectiveness of remote collision detection devices. Current research holds promise for detecting the frequency, number and location of strikes. This technology would provide a cost-effective tool to identify high-collision risk areas, particularly in remote locations. Fourth, research should focus on determining collision risk in wildlife habitats known to support concentrated avian use. This work would further establish relationships between transmission line location and orientation with respect to the surrounding landscape. Finally, there is a need for development of a process designed to gain mutual agreement on an appropriate and structured collision fatality reporting requirement. A consensus-building approach involving researchers, industry, and the regulatory community designed to highlight the mutual benefits to stakeholders may be the most effective means of achieving participation and compliance by all sectors.

Public benefits from this program include a reduction in bird fatalities and, in some cases, factors contributing to bird population declines. California's rich avifauna is a public resource used and enjoyed by millions of residents. Balancing the clear need for electrical power transmission and distribution with stewardship of a valuable natural resource should be the goal of research programs in this focus area. Additional benefits include improved compliance by industry with state and federal laws designed to protect birds and stem population declines. Industry and stakeholder participation in the research identified in this roadmap would also promote partnerships and cooperation towards solving a complex problem.

The applied research recommendations developed for this roadmap are intended to yield tangible products and techniques to directly address collision fatalities and associated population declines. Results could be immediately applied to support collision detection and mitigation efforts. Furthermore, these recommendations should be considered a foundation upon which future research and monitoring could be based. The roadmap attempts to anticipate research questions which might be generated from these recommendations and create a solid base of information from which researchers could design focused investigations to begin answering these questions.

3. Background

Collision with the terminal ground wire (or static wire) of transmission lines has been reported as a primary cause of avian fatality from power line strikes (Meyer 1978, James and Haak 1979, Beaulaurier 1981). Ground wires are installed on transmission lines to dissipate lightning strikes thereby preventing damage to transmission structures and equipment. Fatal strikes may also occur when birds collide with transmission and distribution wires, transmissions tower guy wires, and other structures associated primarily with electrical power transmission.

Accounts of avian fatality from collisions with power lines and utility structures are abundant in the scientific and popular literature. Fatal impacts from these structures have been documented for nearly 350 species (Manville 1999), representing 15 orders and 35 families and subfamilies in 14 countries worldwide and 26 states in the United States (Table 1). In some cases, the level of fatalities attributable to these collisions has been substantial and has contributed to declines in local and regional populations (Mathiasson 1999, APLIC 1994).

Power lines are a seemingly ubiquitous part of the modern landscape. Williams and Colson (1989) estimated that there were approximately 588,447 kilometers (km) (365,644 miles) of power lines in the United States as of 1977; and as of 2000, the Edison Electric Institute (2001) estimated that there were 800,000 km (500,000 miles) of transmission lines alone. Assuming that predictions of tripling of land area for power transmission in the intervening years (Hoover 1978) became true, there may currently be 1,765,341 km (1,096,932 miles) of power lines in the conterminous United States. Applying fatality rates reported in the literature (James and Haak 1979, Faanes 1987, Hugie et al 1993) to these estimates, between 3.5 million and 1.05 billion fatal bird strikes may occur annually in the U.S. from electrical transmission and distribution lines alone. Estimates by Erickson et al (2001) of tens of thousands to 174 million fatalities in the conterminous U.S. from wire strikes are within the range of estimates presented here.

California lacks both data on strike fatalities and studies documenting avian mortality in the state. For a rough estimate of potential strike fatalities in California's Central Valley, researchers used a Geographic Information System (GIS) to obtain information about the distribution of valley transmission lines (Energy Commission unpublished data). The

Central Valley was chosen because it hosts upwards of 800,000 breeding waterfowl annually, with an estimated 5.5 million wintering birds observed in 2001 (Yarris 2001). Waterfowl are considered highly susceptible to wire strikes (Tables 1 and 2).

There are approximately 40,000 miles of transmission lines in California and about 6,320 miles in the Central Valley alone, including about 952 miles that transect National Wildlife Refuges, State Wildlife Areas, and other publicly owned natural resource conservation lands. Applying the mortality rate of 521 fatal strikes/km measured at Mare Island, California by Hartman et al (1993), to the linear extent of transmission lines described above, annual fatality in these areas alone could reach as high as 308,162 birds.

3.1 Summary of Avian Electrocution Research

3.1.1 Factors Affecting Collision Fatality

Avian power line collisions are a widespread problem with potentially significant local impacts when high-risk conditions are present. Understanding the nature of this mortality factor requires the examination of a series of physical and biological factors and of the relationships between these factors that magnify collision hazards. Physical factors include weather, the design and placement of transmission and distribution lines and physiognomic factors which consider the relationship between the geographic location of power lines and the surrounding vegetative communities and land uses. Biological factors include avian morphology, physiology, behavior, and age. A combination of biological and physical factors will most often produce high collision risk.

Table 1. Summary of Families and Subfamilies of Birds for Which Collision Mortality Has Been Documented

Order, Family	*Locations*	*Comments*
Podicipediformes, Podicipedidae (Grebes)	North Dakota, Montana, California	Cassel et al. 1989, Faanes 1987, Hartman et al. 1993, Krapu 1974, Malcolm 1982, McKenna and Allard 1976
Procellariiformes, Diomedeidae (Albatrosses)	Laysan Island, Kauai Hawaii	Bailey 1929, Byrd et al. 1978
Pelecaniformes, Pelecanidae (Pelicans)	Venezuela, North Dakota	Faanes 1987, McKenna and Allard 1976, McNeil et al. 1985
Pelecaniformes, Phalacrocoracidae (Cormorants)	Venezuela, North Dakota	Faanes 1987, McKenna and Allard 1976, McNeil et al. 1985
Ciconiiformes, Ciconiidae (Storks)	Europe, Germany, Rhodesia, South Africa, Uganda Africa, Australia	Council of Europe 1981, Haas 1980, Harwin 1971, Jarvis 1974, Pomeroy 1978, Riegel and Winkel 1971, Rix 1970, Somerset 1972
Ciconiiformes, Ardeidae (Herons, Egrets)	Denmark, Arkansas, Venezuela, England, North Dakota, California, Spain	Alonso and Alonso 1999, Andersen and Block 1972, Faanes 1987, Lano 1927, Ledger et al. 1993, McNeil et al. 1985, Pearson 1993, Scott et al. 1972
Phoenicopteriformes, Phoenicopteridae (Flamingos)	Africa	Ledger et al. 1993
Anseriformes, Anatidae (Ducks, Swans)	Denmark, Illinois, California, Montana, Manitoba Canada, Britain, England, North Dakota, Saskatchewan	Alonso and Alonso 1999, Andersen and Block 1972, Anderson 1978, Arend 1970, Banko 1960, Blokpoel and Hatch 1976, Boso 1965, Boyd and Ogilvie 1964, Cassel et al. 1989, Cohen 1896, Cornwell and Hochbaum 1971, Cornwell 1968, Dedon et al. 1990,

Table 1. Summary of Families and Subfamilies of Birds for Which Collision Mortality Has Been Documented

Order, Family	*Locations*	*Comments*
	Canada, U.S., South Africa, Oregon, Texas, New Mexico, South Dakota, Wisconsin, Missouri, Delaware, Washington, Wyoming, Minnesota, Spain, Sweden	Eltringham 1963, Faanes 1987, Gollop 1965, Harrison 1963, Hobbs and Ledger 1986, Hodson and Snow 1965, Hugie et al. 1993, Krapu 1974, LaBerge 1976, Ledger et al. 1993, Lee 1978, Malcolm 1982, Mathiasson 1999, McDonald 1979, McKenna and Allard 1976, Meyer 1978, Meyer and Lee 1979, Ogilvie 1967, Owen and Cadbury 1975, Pangburn 1945, Pearson 1993, Perrins and Reynolds 1967, Peterson and Glass 1946, Sanderson and Anderson 1981, Schorger 1952, Schroeder 1977, Scott et al. 1972, Siegfried 1972, Sisson 1975, Rasmussen 2001, Thomas 1977, Trauger et al. 1971, Weaver and Ores 1974, Wiese 1979, Wildan Associates 1982, Wilmore 1974, Willard et al. 1977
Falconiformes, Cathartidae (Vultures, Condor)	California, Spain	Alonso and Alonso 1999, Rees 1989, Scott and Jurek 1985
Falconiformes, Accipitridae (Eagles, Hawks, Accipiters)	Utah, California, Spain, Britain, South Africa, Sweden, Norway, Colorado, Nebraska, South Dakota, Florida, England, Ohio, Mississippi, Montana	Alonso and Alonso 1999, Anthony et al. 1994, Austin-Smith et al. 1983, Baldridge 1977, Bromby 1981, Dawson 1974, Faanes 1987, Fernandez and Insausti 1990, Ferrer and De La Riva 1987, Ferrer et al. 1991, Garzon 1977, Glue 1971, Hartman et al. 1993, Hobbs and Ledger 1986, Hugie et al. 1993, Marion and Ryder 1975, Olsen and Olsen 1980, Olsson 1958, Pearson 1993, Platt 1976, Scott et al. 1972, Smith 1985, Snow 1973, Vian 1971, Walker 1916, Zimmerman 1976
Falconiformes, Falconidae (Falcons)	England, Iceland, California, Colorado, Spain, Britain. U.S., South Africa, Australia	Brown 1976, Clausen and Gudmundsson 1981, Drager and Linthicum, eds. 1985, Enderson and Kirven 1979, Ferrer et al. 1991, Garzon 1977, Glue 1971, Herren 1969, Hobbs and Ledger 1986, Newton 1979, Pearson 1993
Galliformes, Phasianidae (Pheasants, Grouse)	Utah, North Dakota, Finland, Norway	Bevanger 1993, Borell 1939, Cassel et al. 1989, Faanes 1987, Heye 1963
Gruiformes, Rallidae (Rails)	California, North Dakota, Texas, Virginia, Britain, Montana, Philadelphia, Spain	Alonso and Alonso 1999, Arnold 1960, Cassel et al. 1989, Dedon et al. 1990, Faanes 1987, Graham 1916, Lemmon 1898, Malcolm 1982, Potter and Murray 1949, Scott et al. 1972
Gruiformes, Gruidae (Cranes)	Idaho, Kansas, Saskatchewan Canada, Texas, Oklahoma, Nebraska, Florida, California, North Dakota, Spain, South Africa	Alonso and Alonso 1999, Drewien 1973, Goodland Daily News 1965, Faanes 1987, Howe 1989, Ledger et al. 1993, Lewis 1974, Nesbitt and Gilbert 1976, Pogson and Lindstedt 1988, McCann 2001, Russell Daily News 1968, Tacha et al. 1978, Walkinshaw 1956, Wheeler 1966
Charadriiformes, Charadriidae (Killdeer) – Recurvirostridae (Avocet)	Denmark, Montana	Andersen and Block 1972, Malcolm 1982
Charadriiformes, Recurvirostridae (Shorebirds)	Denmark, North Dakota, California	Andersen and Block 1972, Pearson 1993, McKenna and Allard 1976
Charadriiformes, Scolopacidae (Shorebirds)	Unknown, California, New York, Saskatchewan Canada, Oregon, North Dakota, Washington, Montana, Australia	Bailey 1929, Cohen 1896, d'Ombrain 1945, Emerson 1904, Faanes 1987, Farnham 1971, Gerstenberg 1972, Gollop 1965, Griepentrog 1929, Hartman et al. 1993, Krapu 1974, Malcolm 1982, Meyer and Lee 1979, Willard et al. 1977
Charadriiformes, Laridae (Terns, Gulls)	Denmark, North Dakota, Britain, Ireland, Quebec Canada, Oregon, Venezuela, California, England, Washington, Montana, Florida, Spain	Alonso and Alonso 1999, Andersen and Block 1972, Cassel et al. 1989, Faanes 1987, Flegg and Cox 1975, Gosselin 1978, Griepentrog 1929, Hartman et al. 1993, Krapu 1974, Lee 1978, Malcolm 1982, McKenna and Allard 1976, McNeil et al. 1985, Meyer and Lee 1979, Scott et al. 1972, Weston 1966, Willard et al. 1977
Strigiformes, Strigidae (Owls)	Denmark, Europe, Washington, Idaho, Switzerland, Sweden,	Alonso and Alonso 1999, Andersen and Block 1972, Council of Europe 1981, Fitzner 1975, Hartman et al. 1993, Herren 1969, Hugie et al. 1993, Olsson 1958, Pearson 1993, Potter and Murray

Table 1. Summary of Families and Subfamilies of Birds for Which Collision Mortality Has Been Documented

Order, Family	*Locations*	*Comments*
	Norway, New Jersey, U.S., California, Oregon, Montana, Spain	1949, Stewart 1969, Willard et al. 1977
Strigiformes, Tytonidae (Owls)	England, Pennsylvania, California, Spain, Canada	Alonso and Alonso 1999, Hartman et al. 1993, Houston 1978, Potter and Murray 1949, Scott et al. 1972
Columbiformes, Columbidae (Pigeons, Doves)	North Dakota, Oregon, Britain, Colorado, Washington, Spain	Alonso and Alonso 1999, Cassel et al. 1989, Faanes 1987, Griepentrog 1929, Meyer and Lee 1979, Scott et al. 1972, Stahlecker 1975
Apodiformes, Trochilidae (Hummingbirds)	Arizona, California	Colton 1945, Hendrickson 1949
Piciformes, Picidae (Woodpeckers)	North Dakota	Faanes 1987
Passeriformes, Tyrannidae (Flycatchers)	Saskatchewan Canada	Gollop 1965
Passeriformes, Laudidae (Larks)	North Dakota, Wyoming, Colorado, California, Spain	Alonso and Alonso 1999, Cassel et al. 1989, Coues 1876, Dedon et al. 1990, Stahlecker 1975
Passeriformes, Hirundinidae (Swallows, Martins)	Arizona, Britain	Anderson 1933, Mead 1979
Passeriformes, Corvidae (Ravens, Crows)	England, Spain	Alonso and Alonso 1999, Holyoak 1971
Passeriformes, Turdidae (Thrushes) Turdidae, Tyrannidae (Kingbirds), Sylviidae, (Gnatcatchers)	Denmark, North Dakota, Saskatchewan Canada, Britain, Oregon, Washington	Andersen and Block 1972, Cassel et al. 1989, Gollop 1965, Meyer and Lee 1979, Scott et al. 1972
Passeriformes, Sturnidae (Starlings)	Denmark, North Dakota, Britain, California, Oregon, Washington, Spain	Alonso and Alonso 1999, Andersen and Block 1972, Cassel et al. 1989, Meyer 1978, Meyer and Lee 1979, Scott et al. 1972
Passeriformes, Parulidae (Wood Warblers)	North Dakota, Saskatchewan Canada	Cassel et al. 1989, Gollop 1965
Passeriformes, Thraupidae (Tanagers)	Saskatchewan Canada	Gollop 1965
Passeriformes, Emberizidae (Warblers, Tanagers, Cardianls, Grosbeaks, some Sparrows)	Denmark, Washington, North Dakota, Saskatchewan Canada	Andersen and Block 1972, Beaulaurier 1981, Cassel et al. 1989, Gollop 1965
Passeriformes, Icteridae (Blackbirds)	Great Britain, Washington, California, Oregon, Montana, North Dakota	Batten 1978, Beaulaurier 1981, Dedon et al. 1990, Faanes 1987, Hartman et al. 1993, Malcolm 1982, McKenna and Allard 1976, Meyer 1978, Meyer and Lee 1979, Pearson 1993
Passeriformes, Passeridae (Old World Sparrows)	North Dakota	Cassel et al. 1989
Otitidae	Germany	Kretzschmar 1970
Non-specific Collision Accounts		Benton 1954, Biosystems Analysis 1990, Dunbar 1954, Jennings 1961, Meyer 1978, Peterson and Glass 1946, Quortrup and Shillinger 1941, Scott 1950, Scott and The Wildfowl Trust 1972, Stout 1967, Stout and Cornwell 1976, Weir 1971

Table 2. Summary of Avian Power Line Collision Mortality Assessment Methods and Mortality Rates

Area Description	*Survey Parameters and Estimate Factors*[1]	*Seasons*	*Mortality Rate*[2]	*Comments (Source)*
3.3-km (2-mile) 150-kV line, Zaanstreek, The Netherlands. Drained pasture land with seasonal wetlands and peat bogs.	150-m transect width, +/- 348 search days. SRB=0.71, 0.70; SB=0.07; HB=n/a; CB=n/a	All	*147/267*	Line transects a 60 ha (148.3 acre) “meadow bird” preserve. (Heijnis 1976)
5.75-km (3.57-mile) 380-kV line, Westzijderveld, The Netherlands.	150-m transect width, +/- 40 search days. SRB=0.71, 0.70; SB=0.07; HB=n/a; CB=n/a	All	*76/79*	Heijnis 1976
1.2-km (0.75-mile) 500-kV line, Lower Crab Creek, Washington. Perennial creek and associated wetlands; pastureland.	100-m transect width, 48 search days. SB=0.13, CB=0.75, SRB=0.36	Fall, Winter, Spring	23/116	Meyer 1978
0.8-km (0.5-mile) 500-kV line, Frenchman Hills Wastewater Site, Washington. “Extensive” wetlands, cattail marshes, swamps; *Artemesia sp*. Scrub.	100-m transect width, 10 search days. SB=0.13, CB=0.75, SRB=0.36	Fall, Winter, Spring	10/77	Meyer 1978
1.15-km (0.62-mile) dual 230-kV lines, Rocky Ford Creek, Washington. Mainly *Artemesia sp*. Scrub. One small portion of line crosses Moses Lake.	100-m transect width, 9 search days. SB=0.13, CB=0.75, SRB=0.36	Fall, Winter, Spring	10/54	Meyer 1978
0.7-km (0.43-mile) 500-kV line, Lower Crab Creek, Washington. Perennial creek and associated wetlands; pastureland.	100-m transect width, 116 search days. SB=0.11, 0.70 [b]; CB=0.73; HB=0.36 [b], 0.32; SRB=0.46, 0.23 [b]. Modified from Meyer (1978)	Fall, Winter	62/533	Major waterfowl flight path between Columbia River and Potholes Reservoir. (James and Haak 1979)
0.4-km (0.25-mile) 500-kV line, Saddle Mtn. Lake, Washington. Intermittent drainage, marsh and riparian habitat.	100-m transect width, 116 search days. SB=0.11, 0.70 [b]; CB=0.73; HB=0.36 [b], 0.32; SRB=0.46, 0.23 [b]. Modified from Meyer (1978)	Fall, Winter	16/246	Line transects the Saddle Mtn. Nat’l. Wildlife Refuge. (James and Haak 1979)
1.1-km (0.68-mile) 230-kV stacked config. line, Bybee Lake, Oregon. Marsh and perennial wetlands.	90-m transect width, 31 search days. Large birds (only). SB=0.33, CB=0.73, HB=0.91, SRB=0.18. Modified from Meyer (1978)	Fall, Winter	8/44	Line transects canal connecting two arms of Bybee Lake. (James and Haak 1979)
0.7-km (0.43-mile) 500-kV line, Lower Crab Creek, Washington. Perennial creek and associated wetlands; pastureland.	100 m transects, 41 search days. SB=0.22, CB=0.74, HB=0.17, SRB=0.10. From James and Haak (1979)	Fall Spring	3/27	Same as James and Haak (1979) above, but w/out ground wires. Bealaurier 1981.
1.1-km (0.68 mile) 230-kV stacked config. line, Bybee Lake, Oregon. Marsh and perennial wetlands.	90 m transects, 29 search days. SB=0.22, CB=0.74, HB=0.25, SRB=0.27. From James and Haak (1979)	Winter, Spring	3/14	Same as James and Haak (1979) above, but w/out ground wires. Bealaurier 1981.
1.9-km (1.2-mile) 230-kV line, Cherry Lake, ND. Grazed native prairie, cropland and emergent aquatic alkali wetlands. Cherry Lake.	90-m transect width, +/- 118 search days. SRB=0.10, CB=0.75, unspecified HB and SB.	Fall, Spring	187/590	Several smaller lakes in vicinity. (Faanes 1987)
1.1-km (0.68-mile) 230-kV line, Kunkel Lake, ND. Grazed native prairie and emergent wetlands. Part of Kunkel Lake.	90-m transect width, +/- 118 search days. SRB=0.10, CB=0.75, unspecified HB and SB.	Fall, Spring	185/1011	Site known for gull, sandhill crane, and goose use. (Faanes 1987)
1.8-km (1.1 mile) 400-kV line, Sibley Lake, ND. Heavily grazed native prairie.	90-m transect width, +/- 118 search days. SRB=0.10, CB=0.75, unspecified HB and SB.	Fall, Spring	178/594	Large wetland with known waterfowl and shorebird use w/in 0.8 km. (Faanes 1987)

Table 2. Summary of Avian Power Line Collision Mortality Assessment Methods and Mortality Rates

Area Description	*Survey Parameters and Estimate Factors*[1]	*Seasons*	*Mortality Rate*[2]	*Comments (Source)*
7.2-km (4.5-mile) 115-kV transmission line, Mare Island, Vallejo, CA. Salt evaporation ponds, estuarine and marine habitats nearby.	61-m transect width, +/- 125 search days. SB=0.27, SRB=0.39, HB=0.27, CB=0.74	All	625/521	Results of 3-year study, 1988–91. (Hartman et al. 1993)
7.2-km (4.5-mile) 115-kV line, Mare Island, Vallejo, CA. Line transects active agriculture (hay production).	61-m transect width, +/- 125 search days. SB=0.27, SRB=0.39, HB=0.27, CB=0.74	All	171/142	Results of 3-year study, 1988–91. (Hartman et al. 1993)
9.2-km (5.7-mile) 230-kV transmission line, Bole Bench, Montana. Annual and perennial grasses and agricultural lands.	+/- 100-m transect width, unspecified search days. SB=0.21, SRB=0.10, CB=0.75. Modified from Faanes (1987)	Fall, Spring	4/2	Near Freezeout Lake Waterfowl Management Area (Hugie et al. 1993)
7.8-km (4.85-mile) 230-kV transmission line, Lake Creek flat near Conrad, Montana. Ponds, swales, wetlands and Lake Creek within study area.	+/- 100-m transect width, unspecified search days. SB=0, SRB=0.10, CB-0.75. Modified from Faanes (1987)	Fall, Spring	20/15	Approx. 3 miles from Benton Lake Nat'l. Wildlife Refuge (Hugie et al. 1993)
1.6-km (1 mile) 500-kV transmission line, San Jacinto Valley, CA. Agricultural lands, riparian habitat and seasonal riverine.	83-m transect width, 55 search days. SB=0.26, SRB=unknown, CB=n/a.	Winter	*13/49*	Pearson 1993
24 spans totaling 10 km (6.2 miles), 380-kV line, Villalpando, Spain. Important waterfowl area.	Approx. 50-m transect width, 26 search days. CB=0.75; SB=0.25[a], 0.67[b]; SRB=0.43[a], 4.0[b].	F/W and Sp/S	1.18/59.0	Alonso and Alonso 1999
33 spans totaling 10 km (6.2 miles), 380-kV line, Duraton, Spain. Abundant Griffon vultures and cliff nesters.	Approx. 50-m transect width, 26 search days. CB=0.75; SB=0.25[a], 0.67[b]; SRB=0.43[a], 4.0[b].	F/W and Sp/S	0.72/35.8	Alonso and Alonso 1999
40 spans totaling 10 km (6.2 miles), 380-kV line, Colmenar, Spain. Important waterfowl and wetland bird roosting area.	Approx. 50-m transect width, 26 search days. CB=0.75; SB=0.25[a], 0.67[b]; SRB=0.43[a], 4.0[b].	F/W and Sp/S	2.42/121.4	Alonso and Alonso 1999
28 spans totaling 10 km (6.2 miles), 380-kV line, Rosalejo, Spain. Extensive plain. Abundant storks and cranes.	Approx. 50-m transect width, 26 search days. CB=0.75; SB=0.25[a], 0.67[b]; SRB=0.43[a], 4.0[b].	F/W and Sp/S	26.8/1339.6	Alonso and Alonso 1999
33 spans totaling 10 km (6.2 mile), 220-kV line, Almaraz, Spain. Extensive plain. Wintering area for cranes; breeding for storks.	Approx. 50-m transect width, 26 search days. CB=0.75; SB=0.25[a], 0.67[b]; SRB=0.43[a], 4.0[b].	F/W and Sp/S	1.78/89.2	Alonso and Alonso 1999
27 spans totaling 10 km (6.2 mile), 220-kV line, Borazas, Spain. Extensive plain. Wintering area for cranes; breeding for storks.	Approx. 50-m transect width, 26 search days. CB=0.75; SB=0.25[a], 0.67[b]; SRB=0.43[a], 4.0[b].	F/W and Sp/S	3.15/157.5	Alonso and Alonso 1999
33 spans totaling 10 km (6.2 mile), 220-kV line, Pto. Lapice, Spain. Important shorebird and waterfowl breeding/wintering area.	Approx. 50-m transect width, 26 search days. CB=0.75; SB=0.25[a], 0.67[b]; SRB=0.43[a], 4.0[b].	F/W and Sp/S	Unk.	Alonso and Alonso 1999
29 spans totaling 10 km (6.2 mile), 220-kV line, Usagre, Spain. Cultivated plain. Important steppe bird area.	Approx. 50-m transect width, 26 search days. CB=0.75; SB=0.25[a], 0.67[b]; SRB=0.43[a], 4.0[b].	F/W and Sp/S	0.18/9.0	Alonso and Alonso 1999

[1] CB=crippling bias, SB=search bias, HB=habitat bias, SRB=scavenger removal bias.

[2] Estimated annual mortality per hectare/per km. *Italics* indicate no crippling bias factor used.

[a] "Small" bird species.

[b] "Medium" or "large" bird species.

Physical Factors

Weather. The literature is replete with documentation of avian wire or tower strike fatality exacerbated by inclement weather. Heavy winds, fog, low cloud cover, rain, hail, and snow contribute to reduced visibility, disorientation, reduced maneuverability, and low altitude flight bringing birds into close proximity with strike hazards (Brown 1993, Elkins 1988, Brewer and Ellis 1957, Banko 1960, Willard et al 1977). Bird concentration during fall and spring migration coincides with periods of unsettled weather that may serve to aid migration (Elkins 1988), but also increases the magnitude of individual weather-related collision events.

In a study of bird strike mortality in The Netherlands along a 3.3 km (2 miles) stretch of 150/380-kV line, Heijnis (1976) noted heaviest fatality during spring hail storms. Anderson (1978), during extensive observations of daily and seasonal waterfowl flights across a transmission line, found that only 1 of an estimated 250,000 birds observed crossing the line struck it during daylight hours and “good” visibility conditions. The remaining 432 strikes were either recorded during inclement weather or at night. Meyer and Lee (1979) noted a marked increase in bird strikes along transmission lines in Oregon and Washington when heavy fog (visibility less than 0.4 km) was present. The authors also noted that flight counts from direct observation are also hampered under these conditions making comparisons based on observational data difficult. Similarly, Brown et al (1987) measured crane strikes along several transmission and distribution lines in the San Luis Valley, Colorado, and noted a strong and statistically significant correlation between inclement weather and increased bird strikes. Likewise, in the Sacramento Valley of California, greater sandhill crane (*Grus Canadensis tabida*) fatalities have been observed under distribution lines following fog events (Brink, pers. comm).

Other authors have noted an increase in strike frequency during fall and winter months, when inclement weather hampers visibility (, Stout and Cornwell 1976, Rusz et al. 1986), or when high winds reduce maneuverability (James and Haak 1979, Hartman et al. 1993) or cause some species, particularly waterfowl, to fly at lower elevations, increasing the potential for collision with wires (Perdeck and Speek 1984). Wind direction has also been identified as a factor affecting collision risk. Perdeck and Speek (1984) found that winds blowing perpendicular to a hazardous line place birds at greater risk of collision than winds blowing parallel to the line.

Because reduced visibility and maneuverability associated with inclement weather increases bird strike frequency, transmission line siting should consider local weather events such as fog and wind. For example, the California Central Valley experiences frequent heavy fog and mortality could be significant around transmission lines placed in or near high-bird-use areas.

Physiognomic Factors. Physiognomic factors affecting avian mortality from power line strikes include the geographic location and direction of a transmission line in relation to natural vegetative communities and land uses of the surrounding landscape

Meyer (1978) hypothesized that avian power line strikes would be more frequent on lines that bisect identical or similar habitat types than they would on those bisecting different habitat types. James and Haak (1979) later refuted this hypothesis. Studies conducted to date and summarized in Table 2 have not sufficiently resolved this hypothesis, or others relating to habitat physiognomy and its relationship to collision risk.

There is some evidence that birds use "flight lanes" during migration and local foraging flights (Bevanger 1994). Birds apparently employ topographical depressions, valleys, linear vegetation breaks, and other features interrupting the visual horizon as directional cues during flight. Forcing horizontal or vertical deviations from these flight lanes, or the resistance by birds in doing so, may be a factor in collision fatalities (Bevanger 1994, Thompson 1978).

In a study of non-hunting waterfowl fatalities in the U.S. and Canada, Cornwell (1968) found an estimated 1,500 of 2,000,000 reported deaths were attributable to collisions with power lines. Results from this study were biased in the sense that collision fatality was tallied incidental to other causes that were the focus of the study. In addition, field recognition of collision fatality is difficult and it is likely that collision victims were attributed to other sources. He suggested fatality could be eliminated along transmission lines passing near wetlands by placing electrical wires underground. Similarly, Malcolm (1982) measured collision mortality along a section of transmission line in Montana constructed over a dry lake bed which subsequently filled with water attracting a large waterfowl population. He recorded 2,530 fatal bird strikes in a 6-month period along the 2-3 mile stretch bisecting the wetland

Mitigation. In South Africa, Ledger et al. (1993) noted collisions with transmission lines by flamingoes (*Phoenicopterus ruber*), cranes (*Grus sp.*) and waterfowl. In a severe fatality case, a transmission line was removed and relocated; in other cases commercially available Bird Flight Diverters (BFD) were installed on offending lines. Ledger et al. (1993) acknowledged the lack of rigorous testing to determine the effectiveness of these devices in this type of application, but added that strike rates and mortality seemed to decrease after installation.

Siting and Corridor Selection. Factors affecting avian fatalities from transmission and distribution line siting include:

- the direct impacts associated with line construction (e.g., change in habitat from land clearing, fragmentation effects, corridor barrier effects, loss of wetlands and other sensitive habitat features and direct impacts to sensitive wildlife and plant species),

- impacts associated with line maintenance (e.g., ongoing road and corridor clearing, impacts to breeding birds from tree trimming and removal, increased noise and disturbance), and
- the direct and indirect effects associated with the presence of lines.

Several researchers have addressed the direct effects of construction and maintenance (see Holberg et al. 1975 for a summary). Factors considered in this section are limited to the direct and indirect effects of the lines once they are constructed.

Past research has resulted in development of suggested location and siting measures design to reduce collision impacts. Scott et al. (1972) recommended erecting lines parallel to known migratory flight paths (as determined in his study by radar data) or burying the line. Ellis et al. (1978) recommended siting power lines away from mountain passes and important migration corridors. Rusz et al. (1986) recommended that, if present, great blue herons (*Ardea herodias*) be given special attention during the siting process and that transmission lines should avoid rookeries or other areas with high heron concentrations.

Although generally not considered a high collision risk due to keen eyesight and high maneuverability, raptors may strike transmission lines under adverse weather or poor visibility conditions. For this reason, Steenhof (1978) recommended locating transmission lines greater than 1.6 km (1 mile) from communal bald eagle (*Haliaeetus leucocephalus*) roosts as these birds would be vulnerable to strikes during frequent take off and landing. Similarly, results of a two year study of crane mortality from transmission line strikes in the San Luis Valley, Colorado, showed that no strikes occurred on transmission lines greater than 1.6 km (1 mile) from feeding areas while 87.8% of strikes occurred when a line either bisected or bordered a major use area (Brown et al 1985).

Removal of abandoned, unused, or obsolete transmission lines would reduce collision hazards in high-risk areas. As part of a review of sources of human impacts to peregrines in Australia, Olsen and Olsen (1980) noted peregrine falcon fatality from wire strikes and recommended removing unused distribution lines near eyries and investigation of alternate routes for new lines in the vicinity of an eyrie.

Ground Wires. A primary cause of avian fatality from power line strikes noted in the literature is collision with the terminal ground (or static) wire of transmission lines. Ground wires are installed on transmission lines to dissipate lightning strikes thereby preventing damage to transmission structures and equipment. Although not as well documented as transmission line strikes, fatalities from distribution line strikes are also a significant cause of strike mortality.

Meyer (1978) and James and Haak (1979) observed that 80 percent of collisions were attributable to ground wire strikes. Studies by Beaulaurier (1981) and James and Haak (1979), conducted along the same sections of transmission line using similar methods and bird mortality estimators, showed substantially reduced fatalities when ground wires were absent. These studies represent compelling evidence that, at least in prairie habitats supporting wetlands and relatively large waterfowl populations, ground wires are a major source of wire strike fatality.

In summary, collisions with ground wires was identified as the primary cause of avian fatality from power line strikes in a few studies. Collision risk increases when transmission lines are located near wetlands, in areas supporting concentrated bird use (e.g., foraging, roosting, or breeding sites), in landscapes with features that concentrate birds into the path of overhead wires, and during inclement weather.

Biological Factors

Biological factors include avian morphology, physiology, behavior, and age. The biological and physiological aspects of birds that predispose some species to increased collision susceptibility have been addressed in several studies (Willard 1978, McNeil et al. 1985, Rusz et al. 1986, Hartman et al. 1993), but no studies have focused solely on these factors as they relate to collision risk. Bevanger (1994) and Brown (1993) provide excellent discussions on this topic and much of the material in this section is summarized from those documents.

Birds are highly adapted to an aerial mode of existence. Examples of specialized structural adaptations that refine flight capabilities to fit a wide variety of geographic, physiognomic, and ecological niches are abundant in the literature (e.g., Cade 1982, Welty 1972). Despite these unique adaptations, the evolutionary process spawning these features has only recently been exposed to power lines and other human-made structures. Therefore, birds still possess limited capabilities in coping with these obstacles.

Avian Morphology and Physiology. Bevanger (1994) suggests that flight behavior and vision are two important factors when considering collision potential. He offered that wing loading (i.e., the ratio of body weight to wing area) and aspect ratio (i.e., the ratio of wingspan squared to wing area) are two parameters that affect flight modes and distinguish the relatively slow flying, soaring species from faster-flying species. Species with relatively high wing loading tend to be faster flyers than those with low wing loading. For example, rails, grouse, pheasants, and waterfowl all have low wing loading, making them more susceptible to wire strikes (Bevanger 1994). This tendency for birds with low wing loading to be at greater risk is supported by the families and orders of birds reported as strike victims in the literature (Table 1). Although wire collisions have been documented in nearly 350 species, the majority are from taxonomic groups with low wing loading and aspect ratio. Body size and corresponding wing length may also contribute to increased strike potential because larger, heavy-bodied birds with longer wings tend to be less maneuverable than smaller birds (Brown 1993, Willard et al. 1977). This trend is supported by the apparent proportion of large-bodied bird families represented in Table 1.

The NUS Corporation (1979) found that species with relatively long legs or necks struck lines more frequently than those with more compact profiles.

The variety of adaptations in vision and visual acuity among birds also suggests susceptibility to wire strikes in some groups. Retinal physiology and fovea[1] number and configuration vary among bird groups in response to the ecological utility to the species. Bevanger (1994) points out that birds with bifoveal retinas (e.g., hirundinids [e.g. swallows], some ciconiiformes [e.g. herons, egrets]) have excellent binocular vision at the apparent expense of a roughly 200° blind spot which may explain why species in these groups strike power lines more frequently than other groups. Similarly, many gallinaceous species lack or possess a poorly developed fovea supporting the observation that gallinaceous birds are apparently particularly vulnerable to wire strikes (Bevanger 1990).

Rusz et al. (1986) noted higher mortality than predicted by local abundance in great blue herons that struck transmission line wires near a cooling pond in Michigan. They noted this species striking a chain link fence during the study and hypothesized that great blue herons may be unable to avoid obstacles during flight due to relatively poor eyesight and flights during dawn and dusk when visibility was low. Brink (2002 pers. comm.) has incidentally observed a number of sandhill crane fatalities from wire strikes at the Consumnes River Preserve in California. The cranes have long necks and long legs that tend to dangle in flight increasing collision risk.

Behavior. Several authors have suggested that birds strike power lines most frequently when engaged in takeoff and landing activities (Willard and Willard 1978, Brown et al. 1987, Scott et al. 1972), while others have cited the simple relationship between strike frequency and the frequency of crossing lines. However, a few studies noted species-specific strike and fatality frequencies that would not be predicted given local abundance (McNeil et al. 1985, Rusz et al. 1986).

McNeil et al. (1985) noted that seabird species-specific mortality from wire collisions was inconsistent with species abundance. Based on carcasses collected during a single day (544), brown pelicans (*Pelecanus occidentalis*), olivaceous cormorants (*Phalacrocorax brasilianus*), royal terns (*Sterna maxima*), common terns (*Sterna hirundo*), and black-crowned night herons (*Nycticorax nycticorax*) exhibited the highest fatalities, yet they were not the most abundant species. McNeil et al. (1985) theorized that pelicans and cormorants made regular foraging flights between Chacopata Lagoon and the Caribbean Sea (Venezuela), which are separated by a road and the transmission line, exposing them to increased risk of collision. During the brief, direct observation phase of their study, two pelicans and a cormorant struck the transmission line lending credence to their theory.

---

[1] The fovea is the area in the eye where visual cells are packed tightly together and the nerve tissue covering these cells in thinnest. The fovea varies in size among species and functions to provide maximum resolution as compared to other areas of the retina, which distinguish features such as color.

In a five-year study of seabird and shorebird mortality along a transmission line near a cooling pond for an inactive nuclear power plant near Midland, Michigan, Rusz et al. (1986) noted that species-specific collision mortality was consistent with local species abundance, except that great blue herons were less abundant than collision rates would predict. They found no apparent correlation between yearly species-specific abundance and mortality.

Bevanger (1994) noted that birds that spend a relatively large proportion of their time in the air would seem to be vulnerable to wire strikes as a consequence of spending increased time in the same spatial plane as wires. He pointed out that while raptors are aerial hunters expending frequent time in the air, often traveling at high speeds, they are not a particularly susceptible group. However, reports of merlins (*Falco columbarius*), peregrine falcons (*Falco peregrinus*) and gyrfalcons (*Falco rusticolus*) striking wires during a stoop or while chasing prey do exist (Brown 1976, Clausen and Gudmundsson 1981, Enderson and Kirven 1979).

Birds that engage in high-speed, low-altitude flights are more susceptible to wire strikes (Brown 1993). Coots, rails, and waterfowl are particularly at risk due to high speed and low altitude flights especially when transmission or distribution lines bisect or border wetlands used by waterfowl for foraging, resting, or breeding (Beaulaurier 1981).

A significant behavioral factor influencing strike potential is flocking or congregation near transmission lines (e.g., Brown 1993, James and Haak 1979, Malcolm 1982). Bevanger (1994) notes that movements to and from lekking grounds and aerial courtship displays near leks expose grouse (*Centrocercus sp.*) to increased risk of wire strikes.

Age. The degree to which age is a factor in wire collision potential remains unclear, although several authors have suggested (and in some cases demonstrated) that juveniles are more susceptible to wire strikes than adults. Supporters of this theory cite lack of flying experience or lack of habituation to an environment with hazards. Brown et al. (1987) found that juvenile cranes hit transmission lines significantly more frequently than adults. McNeil et al. (1985) noted that among five seabird species, juveniles were killed from strikes with transmission lines more frequently than adults. In sampling major wildlife and environmental journals to gather information relating to raptor wire strikes, Olendorff and Lehman (1986) reported that 42 of 76 (55.3 percent) strikes were adults and that 34 (44.7 percent) were subadults. Anderson (1978) showed that juvenile mallards (*Anas platyrhynchos*) were killed more frequently than adults striking transmission lines near a coal-powered electrical plant cooling pond. In contrast, Ogilivie (1967) asserted that age did not affect differential mortality in a study of fatality factors in mute swans (*Cygnus olor*) in England. These studies and others indicate that: 1) there may be species-specific age factors affecting power line strike risk, and 2) these factors could have an effect on local populations of declining or at-risk species.

In summary, certain physiological, physical, and behavioral traits predispose birds to high collision risk. These include: high wing loading, relatively long appendages, eyesight adapted for acuity at great distance (at the expense of short-range acuity), high-speed, low-altitude flights, and age-related inexperience or lack of habituation to hazardous conditions.

3.2 Collision Mortality Assessment

3.2.1 Direct Observations and Dead Bird Counts

As the avian collision problem became more widely acknowledged, researchers and the power generation and transmission industry attempted to quantify collision impacts. Because direct collision counts are labor intensive, and therefore costly, researchers developed methods for quantifying impacts using models and indirect collision evidence. As a result, counting dead birds under transmission lines and determining the cause of death via autopsy was the second best method for assessing levels of impact. Sources of bias associated with this approach include: the inability of searchers to detect every fatal strike victim due to vegetation density (search and habitat bias), scavenger removal (scavenger removal bias), and the possibility of crippling bird strikes that allow birds to continue flight outside of a study area and later die or be killed by predators (crippling bias). Table 2 summarizes studies in which researchers attempted to estimate strike mortality by applying these bias factors to direct counts of strike victims. Although the literature describes several accounts of collisions with power lines (Anderson 1978, McGlauchlin 1977, Banks 1979, Murarka et al. 1976, Meyer and Lee 1979, Smith and Voigts 1993), few attempt to estimate total mortality by applying bias factors and, therefore, may grossly underestimate actual mortality.

Search and scavenger removal biases were first noted by Scott et al (1972) in a study of avian power line strike mortality near Dungeness, England. Scavenger removal trials conducted as part of that study revealed a 50 percent removal rate after 24 hours and 75 percent after 48 hours. However, as described in Table 2, most studies recorded a scavenger removal rate of 75 percent in the first 24 hours. Researchers noted the possibility of increased scavenging intensity near particularly hazardous power lines as scavengers responded to a consistent food supply. This may explain the relatively high scavenger removal rate noted by most authors. Bevanger (1999) describes a "scavenger power-line effect" in which predators may maximize scavenging efficiency by selecting larger, fresher, or more nutritious carcasses. He asserts that particularly hazardous power line segments produce sufficient carcasses to habituate predators to certain prey species or locations. Bevanger (1999) pointed out that scavenger removal trials should be conducted using the same species, or body form surrogates, as those typically killed under the subject power line.

The first effort to quantify impacts accounting for these sources of bias was by Heijnis (1976) in his study of transmission lines transecting peat bog and seasonal wetland habitats in The Netherlands. His work attempted to quantify scavenger removal bias by measuring scavenger removal during trials, using dead starlings (*Sturna neglecta*) in various locations within the study area and documenting the rate at which the carcasses were removed by predators. The study considered habitat or search bias, and vegetative characteristics in the study area allowed for virtually complete detection of strike victims, negating the need to apply this factor to mortality estimates. Similarly, a crippling bias factor was deemed unnecessary in this study after trials involving direct observation of strikes and the distance strike victims traveled defined a relatively wide search corridor (150 meters) in which the author calculated detection of 95 percent of all strikes.

The Netherlands study was followed by studies by Meyers (1978) and James and Haak (1979). Meyers' (1978) comprehensive study included seven sites (three in which mortality were estimated) and incorporated a crippling bias estimating that three of four fatal bird strikes result in continued flight and ultimate fatality outside of the study area. James and Haak (1979) calculated a similar (0.73) crippling bias, and these assumptions were accepted as standard crippling bias factors in a few subsequent studies, including the comprehensive studies conducted by Alonso and Alonso (1999). Crippling bias factors accounted for between 25 and 34 percent of estimated mortality in the studies described in Table 2; a considerably higher fraction of the total estimate than any other factor. If three of four bird strikes result in fatality outside of a study area, then studies omitting this factor are significantly underestimating actual avian mortality.

Faanes (1987) introduced the use of a habitat bias factor intended to account for differences in detection based on habitat type (vegetative cover). This factor may be important in accounting for bird detection in aquatic or tall grassland vegetation, where vegetative structure make it difficult to locate carcasses. Although previous authors identified and, in some cases, defined these factors, Faanes (1987) offered complete descriptions of the factors and calculation algorithms designed to account for each factor in a sequential manner. For example, Faanes (1987) applied the crippling bias factor after accounting for birds that may have been missed as a result of vegetative cover or scavenger removal.

In an attempt to summarize studies for this roadmap, as suggested by Hartman et al. (1993), mortality was calculated per acre and kilometer to facilitate comparison among studies. Bird mortality ranged from 4 to 625 birds per hectare (1.6 to 253 birds per acre) and from 2 to 1,011 birds per km (3.2 to 1628 birds per mile) (Table 2). The highest bird-per-hectare and bird-per-kilometer mortality estimates were in areas supporting wetlands or along transmission lines known to transect bird flyways. However, current studies are biased, because most were conducted in areas known to support relatively large bird communities, were in Wildlife Refuges or Preserves, or had been previously identified as bird flyways.

Although every attempt was made to standardize the data resulting from these studies, each study used different methods, applied different bias factors in different ways, were conducted during different seasons, and had a different focus than the rest. For example, Meyer (1978) focused on behavioral observations to determine collision avoidance and estimated mortality as part of a use-intensity calculation. James and Haak (1979) calculated bias factors, including the crippling bias factor, differently than Meyer (1978). Subsequent authors incorporated variations in mortality estimate calculations to account for site-specific conditions or as a result of author preference. Comparisons of collision impacts require robust data sets; studies will benefit from greater attention to study objectives and design, limitations of data and analyses, and a commitment to carefully document and describe methods (Bevanger 1999).

One additional component required for determining collision impact is a measurement of flight intensity (Bevanger, 1999). To assist in standardizing results and aid in identification of high avian-use areas, several authors measured flight intensity as part of mortality studies (Meyer 1978, James and Haak 1979, Meyer and Lee 1979, Bealaurier 1981, Faanes 1987, Alonso and Alonso 1999) (Table 3). These studies focused on waterfowl flights between roosting or loafing areas and feeding areas, and little documentation of flight intensity is available for other species or wildlife habitat associations and power lines. As with collision mortality estimation, methods varied widely among flight intensity measurement studies, making direct comparison difficult. For example, some researchers used radar-sensing techniques to augment diurnal observations while others relied exclusively on visual accounts. Table 3 provides insight into potential flight intensities for waterfowl from the studies noted above.

Initial attempts to estimate collision mortality have provided a range of mortality values that exhibit considerable variation and have limited utility in broader-scale application. A standardized approach to estimation that appropriately incorporates bias factors would not only enable comparison between studies, but would also shed light on the contribution of other variables to overall mortality.

In summary, estimating strike mortality from dead bird searches requires reliance on several factors that vary considerably in response to local conditions and the species involved. Despite the introduction of error in the estimation process, use and standardization of these factors is essential to improving mortality estimates. Search, scavenger removal, and crippling bias vary widely among published studies and are largely dependent on local factors that may be difficult to assess. In addition, dead bird searches designed to yield statistically valid results are time consuming and often cost prohibitive. Finally, identification of species or site-specific problem areas can be difficult.

Table 3. Summary of Studies Reporting Observed Average Daily Flights and Collision Rates with Power Lines

Area Description	*Seasons*	*Collision Rate*[1]	*Source*
1.2-km (0.75-mile) 500-kV line, Lower Crab Creek, Washington.	Fall, Winter, Spring	248 (0.34)	Meyer 1978
1.1-km (0.68-mile) 230-kV stacked config. line, Bybee Lake.	Fall, Winter, Spring	54 (0.61)	Meyer 1978
0.7-km (0.43-mile) 500-kV line, Lower Crab Creek, Washington.	Fall, Winter	150 (0.65)	James and Haak 1979
0.4-km (0.25 mile) 500-kV line, Saddle Mtn. Lake, Washington.	Fall, Winter	250 (0.51)	James and Haak 1979
1.1-km (0.68 mile) 230-kV stacked config. line, Bybee Lake, Oregon.	Fall, Winter	190 (0.68)	James and Haak 1979
1.2-km (mile) 500-kV line, Lower Crab Creek, Washington.	Fall, Spring	*F=32.5 (<0.01), S=11.7 (<0.01)*	Meyer and Lee 1979
1.1-km (0.68-mile) 230-kV stacked config. line, Bybee Lake.	Fall, Spring	*F=46.9 (<0.01), S=28 (0.03)*	Meyer and Lee 1979
0.8-km (0.5-mile) 500-kV line, Frenchman Hills Wastewater Site, Washington.	Fall	*30 (<0.01)*	Meyer and Lee 1979
1.15-km (0.71-mile) dual 230-kV lines, Rocky Ford Creek, Washington.	Fall	*11.5 (0.03)*	Meyer and Lee 1979
0.8-km (0.5-mile) 115-kV line, Riekkola, Washington.	Winter	*105.5 (0)*	Meyer and Lee 1979
0.7-km (0.43-mile) 500-kV line, Lower Crab Creek, Washington.	Fall, Spring	67 (0.28)	Bealaurier 1981
1.1-km (0.68-mile) 230-kV stacked config. line, Bybee Lake, Oregon. (Before ground wire removal)	Winter, Spring	12 (1.0)	Bealaurier 1981
1.1-km (0.68 mile) 230-kV stacked config. line, Bybee Lake, Oregon. (After ground wire removal)	Winter, Spring	64 (0.58)	Bealaurier 1981
1.9-km (1.2-mile) 230-kV line, Cherry Lake, ND.	Fall, Spring	9.1 (0.74)	Faanes 1987
1.1-km (0.68-mile) 230-kV line, Sheyenne River, ND. Riparian habitat.	Fall, Spring	13.6 (0.08)	Faanes 1987
1.2-km (0.75-mile) 230-kV line, Halfway Lake, ND	Fall, Spring	11.7 (0.11)	Faanes 1987
0.7-km (0.43-mile) 12-kV distribution line, Hendrix Pothole, ND	Fall, Spring	10 (0.13)	Faanes 1987
1.1-km (0.68-mile) 230-kV line, Kunkel Lake, ND.	Fall, Spring	27.8 (0.22)	Faanes 1987
1.8-km (1.1-mile) 400-kV line, Sibley Lake, ND.	Fall, Spring	12.9 (0.4)	Faanes 1987
24 spans totaling 10 km, 380-kV line, Villalpando, Spain. Important waterfowl area.	Fall/Winter Spring/Summer	1484 (0.001	Alonso and Alonso 1999

Table 3. Summary of Studies Reporting Observed Average Daily Flights and Collision Rates with Power Lines

Area Description	*Seasons*	*Collision Rate*[1]	*Source*
33 spans totaling 10 km, 380-kV line, Duraton, Spain. Abundant Griffon vultures and cliff nesters.	Fall/Winter Spring/Summer	5333 (<0.001)	Alonso and Alonso 1999
40 spans totaling 10 km, 380-kV line, Colmenar, Spain. Important waterfowl and wetland bird roosting area.	Fall/Winter Spring/Summer	294 (0.012)	Alonso and Alonso 1999
28 spans totaling 10 km, 380-kV line, Rosalejo, Spain. Extensive plain. Abundant storks and cranes.	Fall/Winter Spring/Summer	852 (0.034)	Alonso and Alonso 1999
33 spans totaling 10 km, 220-kV line, Almaraz, Spain. Extensive plain. Wintering area for cranes; breeding for storks.	Fall/Winter Spring/Summer	3144 (<0.001)	Alonso and Alonso 1999
27 spans totaling 10 km, 220-kV line, Borazas, Spain. Extensive plain. Wintering area for cranes; breeding for storks.	Fall/Winter Spring/Summer	755 (0.013)	Alonso and Alonso 1999
33 spans totaling 10 km, 220-kV line, Pto. Lapice, Spain. Important shorebird and waterfowl breeding/wintering area.	Fall/Winter Spring/Summer	3762 (0.002)	Alonso and Alonso 1999
29 spans totaling 10 km, 220-kV line, Usagre, Spain. Cultivated plain. Important steppe bird area.	Fall/Winter Spring/Summer	1045 (<0.001)	Alonso and Alonso 1999

[1] Average daily flights (collision rate). Collision rate = total estimated collisions/total flights at or below ground wire X 100. *Italics* indicate actual, unadjusted collisions.

3.2.2 Remote Sensing of Avian Power Line Collisions

Remote sensing of avian power line collisions is one method for reducing costs associated with data collection and standardizing strike estimation methods. Remote sensing of collision events would eliminate the need for bias estimates and reduce the time and cost of estimating mortality over several potential problem spans.

Radar technology has been used to monitor avian migration and in other avian studies since the 1960s (Cooper et al. 1991, Gauthreaux 1985, Perdeck and Speek 1984). Recently, this technology has been used to determine both diurnal and nocturnal flight intensity over transmission lines (Pearson 1993, Cooper et al. 1993). Radar can yield reliable estimates of flight intensity, but is incapable of detecting power line collisions and must be used in combination with observations and mortality studies (Cooper et al. 1993).

Research on remotely sensing bird wire strikes began in the early 1980s in response to an assessment of waterfowl collision with the ground wires of the Ashe-Slatt 500-kV transmission line in Oregon and Washington (Smith and Schletz 1991). Wildan Associates (1982), in an effort to improve on and enhance data collected during dead bird searches, developed a prototype impact detection system consisting of an accelerometer mounted to the transmission line ground wire. Information on wire impacts was transmitted to a ground tape recorder data collection system through fiber optics and electrical wire.

The experiment revealed several inherent problems with the system, not the least of which was that a direct connection between the ground wire (in this case energized) and ground could lead to outages and/or user injury. In addition, the accelerometer was too sensitive to distinguish bird strikes from other signals and the data collection and recording device limited data collection to eight hours (Smith and Schletz 1991).

In 1989, Pacific Gas and Electric Company (PG&E) solicited the Edison Electric Institute's (EEI) Roundtable through a questionnaire designed to determine the status and use of remote sensing avian power line strike equipment. PG&E learned through this process that no EEI members or member companies were engaged in research and development activities for this technology. Immediately following summary of the EEI questionnaire, PG&E began research and development work on a remote sensing impact-detection system (Smith and Schletz 1991).

PG&E began trials of a prototype system that consisted of a modified Nitech Power Donut (a donut-shaped device which could be fitted over a transmission line) containing a temperature recording device, a transmitter, power supply, and other electronics which, when coupled with an accelerometer, could transmit line perturbation characteristics to a field module capable of storing information (Smith and Schletz 1991).

Initial tests included launching objects, including sandbags and bird carcasses, from a cannon at energized lines and documenting the impact signature. Trials indicated that more extensive field tests were justified. Although the system could distinguish strikes from spurious signals, its use was limited to energized lines from which it could obtain operating power. In addition, although the system could estimate the energy of the collision, data were not available on the energy generated during a fatal strike, so all strikes were assumed to be fatal (Smith and Schletz 1991, Smith 1993). Later studies by Byrne (2000) found that the monitor as designed did not produce reliable results. New designs are currently being developed and tested (see Section 4.3).

3.3 Mitigation

In 1994, the Avian Powerline Interaction Committee (APLIC) developed methods and guidelines for assessing impact potential, estimating mortality, and siting transmission lines (APLIC 1994). Future guidelines, especially as they apply to study design and data analysis for estimating collision mortality, should follow APLIC 1994, as modified by EDM International, Inc. (2001). The following section outlines those guidelines, as well as those developed by Thompson (1978).

3.3.1 Transmission Line Location and Siting

APLIC (1994) and Thompson (1978) provide excellent overviews of mitigation and avoidance measures for reducing or eliminating collisions with power lines. Transmission line design and placement considerations should follow the APLIC recommendations.

Corridor Selection. Siting transmission and distribution lines can be a very effective—although coarse—method of mitigating avian wire strike fatality. Factors to consider include the presence of wetlands or other special or unique habitat types, river crossings, waterfowl concentration areas, communal roosting areas, migratory flyways, feeding areas, and especially, short distance foraging flyways.

In a comprehensive study of whooping cranes (*Grus americana*), Armbruster (1990) cited Brown et al. (1987) and Faanes (1987) asserting that power lines are a fatality factor for cranes. He recommended a minimum 100-m (328-ft) buffer between riverine roost sites and power line structures. Brown et al. (1987) documented fatality from both transmission and distribution lines, so the buffer width should apply to any power line structure. Accordingly, power lines should not bisect wetlands or other special or unique habitat types, river crossings, waterfowl concentration areas, communal roosting areas, migratory flyways, feeding areas, and short distance foraging flyways; especially if they separate feeding from roosting or breeding habitats.

Centerline Selection. This criterion refers to the actual placement of the transmission or distribution line within the selected right-of-way (ROW). Often, clustering lines in a single ROW can reduce strike potential by reducing the number of ascents and descents required by birds to cross the line. However, if the clustered lines are arranged at varying heights, or are of different construction design, the number of lines in the vertical plane that birds must cross increases, as does strike potential.

Placement of a line near a cliff base or near tree rows (windbreaks) may reduce collision potential by eliminating or reducing the frequency of potential contact with less-visible wires (Hanson 1988). Alternatively, Thompson (1978) suggests planting tree rows near existing power lines that are current hazards, or that bisect or border sensitive habitats.

Several authors, including Thompson (1978), noted the potential benefits of routing lines parallel (as opposed to perpendicular) to prevailing winds. As recommended in APLIC (1994), power lines should be: clustered in both the vertical and horizontal plane to the maximum degree feasible, aligned with existing geographic features or tree lines, and located parallel to prevailing wind patterns.

Underground Construction. Placing distribution lines underground is currently a costly but feasible alternative to overhead wires. The cost increases exponentially when considering underground construction of transmission lines, even though technology for underground construction of high-voltage lines is evolving. Current (2001) estimates for construction costs for overhead 230-kV transmission lines are about $1 million per linear mile, whereas underground construction for the same line could be 4–10 times greater. Underground construction for 230-kV transmission lines have cost $6 million per linear mile in California (M. Hesters, pers. comm.) In addition, environmental impacts more severe than wire strikes (e.g., direct habitat loss or potential introduction of hazardous materials into ground water) could result from underground construction in some cases.

Despite the pitfalls associated with installing transmission and distribution lines underground, several European countries have begun burying lines. Bayle (1999) found that in the early 1990s, 77 percent of all transmission lines in Belgium were underground, with Germany (56 percent) and the United Kingdom (44 percent) not far behind. Italy, France, and Spain had 22 percent, 19 percent, and 13 percent underground lines, respectively.

Tower Design. Free-standing towers that do not require guy wires present a lower strike potential than guyed structures, as guy wires introduce an additional collision hazard.

Thompson (1978) also discusses adjusting conductor height to avoid known flyways or flight approach paths. Minimum height requirements to accommodate inter-tower sag and economic feasibility place lower and upper height constraints on tower construction. Because flight paths and flyway altitudes are difficult to measure or predict, Thompson (1978) suggests that this may not be an effective form of mitigation.

Ground Wire Removal. Collision potential could be reduced by eliminating ground wires in sensitive areas and where not essential for lightning strike damage abatement. In their evaluation of collision avoidance and reduction mitigation measures, Beaulaurier et al. (1982) suggested that removal of ground wires was the most effective avoidance measure in most cases, although marking the ground wire reduced collisions by an average of 45 percent, based on studies that reported collision mortality estimates. The authors also noted that often studies did not combine flight intensity observations and measurements with mortality estimates, making precise reduction estimates difficult. In a Colorado study, crane strike mortality was substantially reduced along a transmission line where the ground wire was experimentally removed (Brown et al. 1987).

To date, ground wire removal has been the most effective long-term solution to reducing bird collision fatalities in prairie habitats where a transmission line bisects foraging and roosting habitat. Additional research is needed to clarify the role of ground wire removal in reducing collision fatalities under other siting and habitat conditions. Although removal could be costly, prioritization of problem sites and selective removal could substantially reduce the hazard at a relatively low system-wide or project-wide cost. Although not specifically recommended in APLIC (1994) or other literature, removal of ground wires from transmission lines in areas with <10 isokeraunics (thunderstorm days per year [NOAA 2001]) could significantly reduce collision hazard in California.

3.3.2 Diversion Devices

Placing wire underground is the only available collision avoidance measure, and ground wire removal is the best mitigation measure; however, recognition of these activities' cost and technical feasibility limitations have spawned attempts at other forms of mitigation for existing transmission lines. These measures are usually aimed at increasing the visibility of a ground wire which, in theory, would divert birds away from the hazard.

While some designs and diversion device applications have been effective in reducing collisions, these devices have limited value under poor visibility conditions. A few attempts at other types of diversion devices, including effigies and cannons, have met with little success and are more costly than simple diversion devices. Table 4 summarizes a complete account of published diversion devices and provides a description of each type. The following discussion details device design, installation methods, and target species.

Table 4. Summary of Devices to Increase Power Line Visibility

Device Name	*Description*	*Comments*
Spiral Vibration Dampener (SVD)	Extruded plastic spiral device that fits over a ground wire.	Does not retain color and may become brittle.
Bird Flight Diverter (BFD)	Spiral device made from high impact PVC which attaches over ground wire.	Comes in 4" and 8" sizes; tested effectiveness.
Swan Flight Diverter (SFD)	Similar to the BFD but larger	Effective in some applications
Bird “flapper”	Pendant oblong device with four fins painted black and white on alternating surfaces	Used in South Africa. Apparently less expensive to install than BFDs
Avifaune Spiral	Similar to BFD, but in red and white colors.	Not available in U.S. and testing limited.
Aerial Marker Spheres	Various size and color spheres that attach to ground wires	Apparently effective. Installation cost greater than BFDs.
Swinging plates	Plates of various sizes and colors that attach to, and hang from, ground wires.	Attachment point may wear ground wire.
Ribbons, tapes, etc.	Various lengths, widths, and colors of hanging ribbon or plastic to increase wire visibility.	Effective in some cases. Durability may be a problem.

Moorehead and Epstein (1985) recommend collision avoidance and reduction measures as part of the design and siting of small-scale electrical generation and transmission facilities in Oregon. These measures could include placing wires underground, installing “highly visible” flags or marker balls on lines, eliminating ground wires where lines cross wetlands and migration routes, constructing lines parallel to prevailing winds and lower than flight corridors, and crossing rivers at an oblique, instead of right, angles.

Miller (1993) describes the U.S. Fish and Wildlife Service (USFWS) requirement for attachment of 23-cm orange aerial marker spheres placed at 34.8-m (100-ft) intervals along ground wires (at alternating intervals on adjacent lines). The intention of the Service’s recommendations were to place the devices in areas deemed as high strike hazard areas (e.g., known flyways, wetlands, or areas with other special conditions). Orange spheres were used at Modoc National Wildlife Refuge in northern California and at Malheur National Wildlife Refuge in southeastern Oregon to reduce sandhill crane collisions; however, the efficacy of this action was never monitored (S. Clay and G. Ivey, pers comm.).

Scott et al. (1972) suggested using corks, colored balls, and 15-cm-long black tape streamers at 1.9-m (6-ft) intervals along the ground wire on transmission lines. Initial results showed a substantial decrease in fatal strikes when using the tape streamers. In separate trials in this study, the researchers wrapped "luminous" orange tape at 1.2-m (4-ft) intervals around the ground wires of two sets of lines and compared mortality on these lines to two control lines in the same vicinity with the same orientation and height. The results revealed no differences in mortality between the control and treatment lines. McNeil et al. (1985) recommended following Scott et al. (1972) recommendations, particularly with respect to constructing transmission and distribution lines parallel to know foraging or migratory flyways. They also recommended avoiding wetlands, lakes, lagoons, and other waterways.

The Bird Flight Diverter (BFD), a line marker 7–15 inches long with spirals, was first tested in the early 1980s in the Netherlands (Brown and Drewien 1995). Depending on the spacing between markers, fatalities were reduced from 57 to 89 percent on lines marked with BFDs. Swan Flight Diverters (SFD) are larger and longer versions of the BFD, but these have not been tested extensively in the field. Crowder and Rhodes (2001) are in the process of assessing mortality and the effectiveness of SFD in a study in southwestern Indiana along a stretch of transmission line apparently noted for high heron and egret fatalities.

Brown (1993) and Brown and Drewien (1995) conducted a rigorous study comparing the effectiveness of yellow swinging plates, yellow Spiral Vibration Dampeners (SVDs), and increasing ground wire size to control sites (without diverters) for reducing collision fatalities involving cranes. The study site had a history of substantial crane fatalities and presented an opportunity for determining differential effectiveness of the devices. More than doubling ground wire diameter proved completely ineffective, but the authors noted a 63 percent and 61 percent reduction in strikes with use of swinging yellow plates and yellow SVDs, respectively.

Difficulties in comparing study results due to differing study designs make recommendation of a specific device infeasible. More research is required to determine the device best suited to a given set of environmental conditions and species intended for protection. Table 5 summarizes studies in which the effectiveness of some of these devices was tested, the study results, and comments related to improving device effectiveness.

Bird Flight Diverters should be subjected to rigorous testing under a variety of environmental conditions, to determine the most effective applications. These devices combine the benefits of horizontal line coverage with the visibility of an enlarged vertical span and appear promising from a cost perspective. Also, current BFD manufacturers claim longer field life than the SVD or prior versions of the BFD, which were made of less durable materials.

Table 5. Summary of Power Line Diversion Device Studies and Device Effectiveness

Mitigation Measure and Specifications	*Location/ Species*	*Power Line Characteristics*	*Effectiveness*	*Source*
Bird Flight Diverter/Spiral Vibration Dampeners				
Bird Flight Diverter (BFD)	The Netherlands/ shore and sea birds, passerines	Twin 150-kV and 380-kV	"…brought little or no results."	Heijnis 1980
BFD	Unknown	Unknown	57%–89% collision reduction	Brown 1993
BFD	South Africa/ waterfowl, flamingos, cranes	Transmission	Lacked rigorous testing, but collisions "…seemed to decrease after installation."	Ledger 1993
Red spiral BFD	Spain/several	Transmission, 380-kV with dual overhead ground wires.	60% reduction in collisions and 61% reduction in flight intensity.	Alonso and Alonso 1999b
Yellow Spiral Vibration Dampener (SVD)	Colorado/ cranes	Transmission	61% reduction compared to unmarked line.	Brown and Drewien 1995
Swan Flight Diverter (SFD)	Wisconsin	Distribution, 23.9 kV	Eliminated collisions completely	Rasmussen 2001
Bird "flapper"	South Africa, cranes	Transmission	"More effective than the BFD.."	McCann 2001
Pendent Plastic Strips				
1.5-cm black tape	England/ gulls, passerines	Transmission	Reduced collisions.	Scott et al. 1972
5-cm ground wire strips	England/ gulls, passerines	Transmission	Not effective.	Scott et al. 1972
White ribbons on ground wire	Germany/ unknown	Transmission	28% reduction, compared to unmarked line.	Renssen et al. 1975
Black ribbons on ground wire	Germany/ unknown	Transmission	48% reduction, compared to unmarked line.	Renssen et al. 1975[1]
Black and white ribbons on ground wire	Germany/ unknown	Transmission	52% reduction, compared to unmarked line.	Renssen et al. 1975
Black and white plastic strips on ground wire	The Netherlands/ shore and sea birds, passerines	Twin 150-kV and 380-kV	Reduced collisions.	Heijnis 1976
50-cm and 10-cm wide yellow streamers on conductors	Denmark/ unknown	Transmission	37% reduction compared to unmarked line.	Glystorff 1976
Plastic strips. Installation unspecified.	The Netherlands/ shore and sea birds, passerines	Twin 150-kV and 380-kV	"…Brought little or no results."	Heijnis 1980

Table 5. Summary of Power Line Diversion Device Studies and Device Effectiveness (cont'd)				
Mitigation Measure and Specifications	***Location/ Species***	***Power Line Characteristics***	***Effectiveness***	***Source***
Spheres				
Orange spheres	Germany/ unknown	Transmission	No collision reduction.	Renssen et al. 1975[1]
Fishing floats	England/ unknown	Transmission	Collisions nearly eliminated.	Kaiser and McKelvey 1978
Orange aluminum spheres. Installation unspecified.	South Africa/ waterfowl, flamingos, cranes	Transmission	Unknown.	Hobbs and Ledger 1986
Glowing fluorescent marker. Installation unspecified.	South Africa/ waterfowl, flamingos, cranes	Transmission and guy wires	Unknown.	Hobbs and Ledger 1986
Plastic balls. Installation unspecified.	South Africa/ waterfowl, flamingos, cranes	Distribution lines	Unknown.	Hobbs and Ledger 1986
30-cm yellow spheres with black vertical stripe. Placed at irregular intervals.	Nebraska/ cranes	69-kV Transmission	Significantly reduced collisions ($P<0.01$)	Morkill and Anderson 1993
Luminous or Colored Bands or Spacers				
5-cm wide luminous orange bands	England/ gulls, passerines	Transmission	Not effective.	Scott et al. 1972
Orange spacers between sub-conductors	Germany/ unknown	Transmission	60% reduction, compared to unmarked line.	Renssen et al. 1975
Yellow tubes	Japan	Transmission	Collision reduction.	Archibald 1987
Increase Ground Wire Diameter				
Increase ground wire size from 0.914 cm (0.360 in) to 2.51 cm (0.990 in).	Colorado/ cranes	115-kV Transmission	Not effective.	Miller 1993, Brown 1993b
Plates				
Yellow swinging plates	Colorado/ cranes	Transmission	63% reduction compared to unmarked line.	Brown and Drewien1995
Effigies/Other				
Red or silver raptor effigy. Installation unspecified.	The Netherlands/ Shore and sea birds, passerines	Twin 150-kV and 380-kV	"...proved more successful [than a BFD]."	Heijnis 1980
Decoy distribution line poles. Installation unspecified.	South Africa/ waterfowl, flamingos, cranes	Distribution lines	Unknown.	Hobbs and Ledger 1986

3.4 Collision Study Design

As previously discussed, past collision studies have utilized a wide variety of methods, making it difficult to compare results and determine their significance. The most frequent problem with studies designed to estimate collision mortality is the omission or differential application of bias factors. Search capabilities, carcass delectability, and removal of carcasses prior to detection by researchers can substantially affect results.

A few studies have attempted to incorporate these factors; however, researcher preference and study design assumptions have resulted in variations in how bias factors are applied.

The following guidelines are based on a thorough review, recalculation, and analysis of results from past studies:

1. Standardize power line collision mortality study designs to include the bias factors and algorithms for applying them that APLIC has developed (APLIC 1994), and employ the statistical treatment and considerations outlined by Hartmen et al (1992).

2. Encourage studies that are designed to estimate bird strike mortality at both control and treatment sites, as in Hartman et al. (1993).

3. Emphasize studies that test transmission line route habitat relationships. Although collision fatalities have been documented most frequently where transmission lines cross water or riparian habitats, little is known about the effects of those crossing other habitats.

4. Encourage studies that test physical factors that may affect bird-strike frequency, including weather, line orientation, wind, and proximity to landscape features that may affect strikes.

5. Collision mortality study design should be capable of expressing results as estimated fatalities per distance unit of transmission line, compared to diurnal and nocturnal crossing frequency (e.g., estimated birds/km = x% of birds crossing line).

Additional study considerations (summarized from APLIC 1994):

1. Studies should evaluate habitat characteristics, bird species composition and relative abundance, and daily and seasonal habitat use.

2. Study design should consider factors contributing to fatalities from all sources (e.g., vehicle collision and shooting).

3. Researchers should evaluate line visibility and the frequency of events affecting visibility (e.g., fog, sleet, and snow) and considered them as part of developing a study design.

3.5 Biological Significance

Alonso and Alonso (1999) concur with other authors (e.g., Meyer 1978, James and Haak 1979, Faanes 1987) that collision fatalities are not a population decline factor and has little population-level significance, except in areas where birds are concentrated for breeding or roosting and for species with naturally low populations or for species whose populations are threatened or endangered with continued existence. Although not considered a population-level decline factor (except as noted above), Mathiasson (1999) noted that collision mortality in swans in Sweden was probably sufficiently high to be a significant cumulative factor when considered with other human-induced fatality factors. Similarly, McCann (2001) noted that collision fatalities did exert a population level effect on wattled cranes (*Bugeranus carunculatus*) in South Africa accounting for 38.6% of all crane fatalities. Bevanger (1999) asserts that collision mortality is still considered insignificant in most areas largely because recovery of dead birds is a superficial measure of the magnitude of the problem as most power lines are in remote areas and, therefore, most fatalities go undocumented.

Continuing interest in the collision fatality issue has raised awareness to a point where researchers are considering ways to measure how significant this fatality factor is to bird populations. Once remote sensing techniques have been refined and become cost-effective for use on long transmission line segments (or on multiple segments simultaneously), researchers could document effects across a range of environmental conditions and use them as a basis for collision risk modeling. In turn, modeling could form the foundation for more reliable and defensible estimation of population-level effects. This type of modeling would require the results of a series of baseline studies in California, which are currently lacking, and is beyond the timeframe addressed in this Roadmap.

3.6 The California Perspective

Few published studies describe and document the avian power line collision problem in California. Reports of avian collision incidents or studies attempting to quantify the problem and identify potential problem areas exist primarily as internal company reports (e.g., Pearson 1993, Hartman et al. 1993) and are generally lacking in the literature. The lack of readily available information on avian power line collision fatalities in California is especially alarming, considering the rich biological diversity of the state, the intense use of the Central Valley by migratory waterfowl, the migratory pathways documented along California's north-south axis, and the regular fog and reduced visibility in the Central Valley. These factors suggest power line collision fatality may be significant in California.

Currently, there are no requirements for reporting or documenting collision fatalities in California (Linda Spiegel, pers. comm.). As pointed out by Bevanger (1999), a reason why the scope and magnitude of avian collision fatalities is perceived as negligible could be a lack of data and other information identifying problem areas.

The most comprehensive collision mortality study in California was conducted by Pacific Gas and Electric Company (PG&E) along a 7.2 km (4.5 mile) section of 110-kV transmission line transecting estuarine, wetland, and agricultural lands near Vallejo (Solano County; Hartman et al. 1993). This study documented among the highest mortality (dead birds/km) of all of the nationwide studies summarized in Table 2. The significance of these results are apparent when considering that the configuration of this transmission line and its position and orientation in relation to wetlands is replicated many times throughout the Central Valley. The potential for ongoing, widespread collisions is significant, considering that most transmission lines in the Central Valley were constructed with the single- or dual-terminal (two parallel ground wires mounted on top of the transmission line structure) ground wires (Al McCuen, CEC pers. comm.) that have been identified as a culprit in collision fatalities (e.g., APLIC 1994, Meyer 1978, James and Haak 1979, Faanes 1987, Hartman et al. 1993).

The Central Valley falls within the Pacific Flyway and is one of the flyway's most important waterfowl areas. In an average year, the Central Valley supports 100 percent of the world's population of Aleutian Canada geese (*Branta canadensis leucopareia*) and tule white-fronted geese (*Anser albifrons gambelli*); 80 percent of North America's Ross's (*Chen rossii*) and cackling Canada geese (*Branta canadensis minima*); and, 65 percent of the North America's tundra swans (*Cygnus columbianus*), pacific white fronted geese (*Anser albifrons*), and northern pintail (*Anus acuta*). As previously noted, there have been few studies to determine wire strike mortality in California, and none in the Central Valley, where wintering concentrations of waterfowl, frequent winter fog, and about 20 percent of the state's transmission lines create a potential for considerable fatalities.

Outside of the Central Valley, collision fatalities involving young California condors (*Gymnogyps californianus*) released as a part of an intensive recovery effort have been documented near the Los Padres National Forest in southern California. Recently, collision fatalities involving turkey vultures (*Cathartes aura*) and Canada geese are being noted by Pacific Gas and Electric.

The significance of fatalities on breeding or wintering bird populations depends on several factors, including local weather and physiognomic conditions, potentially affected species, annual migratory patterns, and configuration of transmission lines. However, the relatively high biological diversity of California, and the fact that fatalities have been documented in 16 of 38 (42 percent) bird families and subfamilies (Table 2), suggests the potential for population-level affects. The lack of studies to determine collision mortality and the effectiveness of diversion devices and other mitigation techniques—despite the high number of documented collision events (Table 2)—points to the need for a focused and sustained research effort in California.

3.7 The Legal Context

In the United States, most birds are migratory, and as such, are protected under the Migratory Bird Treaty Act (MBTA; 16 U.S.C. 703–712), which prohibits "take" of migratory birds. Raptors are further protected by the Bald and Golden Eagle Protection Act (16 U.S.C. 668–668C) and, in instances where a species is federally listed as threatened or endangered, the Endangered Species Act (16 U.S.C. 1531–1543). Violations of these laws can result in criminal penalties of up to $15,000 and six months imprisonment, or both, for misdemeanor violations and $250,000 and two years imprisonment, or both, or felony violations.

In California, birds may be further protected by the California Endangered Species Act (Fish and Game Code Section 2050–2097), special provisions for take or destruction of bird nests or eggs and, in particular, raptor nests or eggs (Fish and Game Code Sections 3503–3503.5), state extension of the MBTA and fully protected species clauses (Fish and Game Code Section 3511–3513), and, to a lesser degree, the California Environmental Quality Act (CEQA; Public Resources Code 21000–21177). Penalties for violation of these laws vary, but can result in fines of up to $10,000.

The Wilderness Act of 1964 required protection of wilderness values on some refuges, which precludes intrusion of human-made, structures including power lines. The National Wildlife Refuge System Administration Act of 1966 gave official designation to the National Wildlife Refuges as a system and provided the means for the Regional Director to approve power lines that are judged to be compatible with the primary purpose of the refuge.

The USFWS (1978) developed policy on power line construction and remediation on Wildlife Refuge land. It is summarized as follows:

1. While each proposal must be considered, no new overhead power or communication lines will be permitted on National Wildlife Refuges unless they are found compatible with the purpose of the refuge and approved in writing by the Regional Director. Wherever possible, existing overhead lines will be removed or modified to achieve this compatibility.

2. Environmental impacts on the Nation's fish and wildlife resources will be assessed and recommendations made on a case-by-case, site-specific basis on proposed power and communication lines on all other lands, including those in private ownership. The recommendations will include a priority ranking of acceptable alternatives to avoid key wildlife areas. Where conflicts cannot be avoided, action will be recommended to compensate or mitigate the anticipated loss of wildlife values. Habitats critical to the survival of endangered species cannot be adversely modified.

3. Every effort will be made to work with utility companies in providing early input to assist in planning the least environmentally sensitive route alignments for power lines.

There have been few court cases in which damages were sought for direct impacts to birds from wire strikes. A 1968 case (*Central Illinois Light Co. v. Mary Allen Porter et al.*) litigated power line strike impacts to waterfowl and as a result the Central Illinois Duck Club was awarded $49,000 in damages (Quigley 1977).

3.8 Issues Summary

Avian fatalities as a result of collision with electrical transmission lines was first identified in the late 1800s, coinciding closely with erection of the first communication and electrical distribution pole systems. The proliferation of transmission lines in the United States and throughout the world suggests the problem is increasing and can be a significant source of fatality especially in particularly hazardous areas. Collisions are most frequently associated with transmission lines and, in particular, ground wires placed at the top of transmission towers for lightning damage abatement purposes. However, collision fatality has been documented along distribution lines in North America and other parts of the world as well.

Species with relatively large body size, long appendages, and relatively poor eyesight are most susceptible to wire strikes. Collision risk or hazard is affected by physical, physiognomic, and biological factors. Power lines that transect or parallel areas concentrating birds (e.g., wetlands, riparian areas) or those separating areas used for different life history functions (e.g., breeding, foraging, or roosting) are the most hazardous. In cases where hazardous designs are coupled with high bird use and habitat factors, fatalities may be substantial and ongoing. In addition, regions that commonly experience inclement weather, such as fog or wind, particularly during periods of high bird use, are likely experiencing a high number of collision incidents that are largely undetected.

At sites where ground wires are identified as the primary fatality source, removal of the terminal ground wire on transmission towers is the most effective means of reducing collision mortality. In some cases, Bird Flight Diverters and other line marking devices have proven effective in reducing collision impacts. Additional research is needed to determine the most effective designs and applications from both a risk-reduction and cost-containment standpoint.

3.9 The PIER Focus

As noted throughout this roadmap, there is a lack of data on avian collisions with power lines in California, as well as on the effectiveness of mitigation technologies and strategies for specific bird populations and environments. A regulation requiring power line companies to report avian collisions with power lines would greatly facilitate researchers' ability to understand the causes of these collisions, better identify problem areas, and develop and implement effective mitigation.

Part of the mission of PIER is to conduct and fund research in the public interest that would otherwise not occur. As evidenced by the lack of current information and ongoing research, avian collisions with power lines is one such issue. It is in the public interest to developing methods and technologies that reduce avian collisions with power lines. PIEREA will address this topic through its own targeted research and hopes to identify collaborators that will share data and work with it to develop mitigation strategies and technologies.

PIEREA is also developing roadmaps to address avian electrocution with power lines and avian interactions with wind turbines. 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 preceding section set forth the physical and biological characteristics influencing power line collision risk and described actions intended to avoid and mitigate this risk. This section summarizes research currently being conducted and research needed to address avian/power line collision risks. The research areas listed below are based on responses to the questionnaire developed to involve the advisory team in the process and on CEC knowledge of the issue area. Section 5 outlines PIER's suggestions for specific research to address these needs.

At present, research needs to focus on expanding our knowledge of the problem, identifying and refining avoidance and mitigation measures, and developing new detection technologies.

These research areas are:

1. Standardizing Mortality Estimation
2. Testing and Documentation of Diversion Device Efficacy
3. Testing and Documentation of Remote Collision Detection Devices
4. Determine Collision Risk Levels Associated With Potential High-Avian-Use Habitats
5. . Long-term Monitoring and Reporting

PIEREA has recently entered into an interagency agreement with UC Santa Cruz, Predatory Bird Research Group to initiate an Avian-Transmission System Mitigation Program. The purpose of this program is to support research on the development and application of methods and technologies that reduce and resolve negative impacts from avian interactions with transmission systems. Awarded projects are required to be consistent with the research goals identified in this roadmap and with PIEREA's roadmap on avian collision with power lines in California.

Avian power line collision fatality issues have been the topic of numerous popular articles and studies, yet those issues remain largely undocumented within the industry and regulatory communities. Industry awareness often focuses on the financial and service interruption aspects, whereas the regulatory community is concerned with exceptional fatality cases or those affecting declining or vulnerable species. The APLIC (1994) document increased awareness of avian power line collisions, but a more comprehensive and outreach-based approach is needed to align all views and needs, and to focus attention on solutions.

Dissemination of research results, field trials of new mitigation devices, and effectiveness of remediation measures has been hampered by a lack of publication in the scientific literature. Often, industry and the regulatory community are unaware of significant progress in the field and important work may be overlooked. APLIC has conducted periodic workshops on avian collision issues that have helped focus attention in the research community. However, a more comprehensive and scientifically based approach is needed to move forward a meaningful research program.

4.1 Standardizing Mortality Estimation

Evaluating the biological significance of collision fatality and comparing mortality estimates between studies has been hampered by the differential application of bias factors, lack of flight intensity data, and use of disparate methods. Solving this recurring problem has been identified recently as a top need by researchers (Lehman 2001, Bevanger 1999).

Currently, no research is being conducted to address this issue.

Research Needs

1. Research should focus on critical evaluation of study designs and methods employed in the collision mortality studies described in Table 2 to develop a standardized and consistent approach to future investigations. Mortality estimation research then should be focused on high risk areas within California to determine effectiveness under typical collision risk conditions. (See 5.1.1)

4.2 Testing and Documentation of Diversion Device Efficacy

Many types of devices have been employed in an attempt to divert birds from ground wire impacts (Table 4). In some cases, researchers conducted follow-up investigations to determine the effectiveness of these devices and results varied (Table 5). Despite these efforts, comprehensive studies, conducted under a variety of field conditions, are lacking.

PIEREA is currently co-funding a study at the Audubon National Wildlife refuge in North Dakota to document the effectiveness of some diversion devices. PIEREA is also working with PG&E, The Nature Conservancy, CSU Sacramento, and a private land owner to conduct a study on the effectiveness of diverters in an area that has greater sandhill crane collisions with distribution lines. This study should begin in winter 2002/03.

Research Needs

1. Rigorous testing is needed to determine the species-specific effectiveness of devices, their durability under varying field conditions, and their application on various transmission line designs, particularly regarding their application in California. Future studies should incorporate the techniques and methods described in Brown (1993) and Brown and Drewien (1995). (See 5.1.2)

4.3 Testing and Documentation of Remote Collision Detection Devices

Remote sensing of bird-power line strikes would provide for efficient data collection over broader line spans and concurrent collection within identified problem spans. Current dead bird search methods and mortality estimation are time consuming and costly, and they rely on bias factors which are often crude or inaccurate. In addition, measuring flight intensity is often cost prohibitive and the lack of these data make significance determination impossible. Remote sensing could well be the long-term solution to cost-effectively identify high-collision-risk areas and monitor remediation and mitigation measures.

A current project funded by PIEREA and the Electric Power Research Institute (EPRI) is developing and field-testing two automated line monitors: the Bird Strike Indicator (BSI, for detecting strikes) and the Bird Activity Monitor (BAM, for measuring flight intensity) (Carlton 2001). The study includes a quantitative and replicable method for estimating mortality. Future research following the study design (outlined by EDM International, Inc. through EPRI) to determine the feasibility and efficacy of the BSI and BAM systems will yield the information needed to apply and use these systems properly.

Research Needs

1. Research should be emphasized on studies that test remote sensing devices to ascertain the range of device effectiveness. These tests should be conducted under a variety of field conditions (e.g., crossing wetlands and in both high- and moderate-use areas) and with different species groups. (See 5.1.3)

4.4 Determine Collision Risk Levels Over Potential High-Avian-Use Habitats

Collision risk has been clearly documented as a problem in other states where transmission lines with hazardous designs bisect or parallel wetlands used for foraging and roosting by waterfowl (Meyer 1978, Thompson 1978, Bevanger 1994). Risk potential also increases as the proximity of hazardous line designs to communal roosts or other congregation areas decreases (Steenhof et al. 1993, Bevanger 1994). However, little is known of collision rates in wetland areas in California or where hazardous lines bisect or parallel other habitat types such as riparian, lacustrine or ecotones between terrestrial habitat types. As with other aspects of the collision fatality problem, the lack of this type of information is particularly true of California.

Currently, no research is being conducted to address this issue.

Research Needs

1. Research should focus on examination of collision rates in areas where hazardous lines bisect or parallel habitat types (e.g., wetland, riparian, lacustrine, or ecotones between terrestrial habitat types). This work should be conducted at potential high-avian-use habitats in California. (See 5.1.5).

4.5 Diversion Device Implementation

Many diversion devices are available, but the individual effectiveness of this equipment remains largely untested. Determining the effectiveness of diversion devices is the first step in identifying solutions to the collision problem. For an implementation program to be effective, it must combine the findings of device-effectiveness studies and identify high-risk sites. System-wide remediation is not possible, but solutions from short-term need research projects will help to direct implementation. Creating a plan for implementation which combines the findings of device effectiveness studies and identification of high-risk sites is essential to maximize the effectiveness of an implementation program. In California, development of an implementation plan should include industry and regulatory community representatives to ensure feasibility and cooperation.

Research Needs

1. Based on the results of research recommend in 4.3 and 4.4 research, develop a implementation plan that identifies high priority areas for installing collision deterrent devices on power lines (5.2.4).

4.6 Long-term Monitoring and Reporting

Few collision mortality studies have incorporated a monitoring component to determine the effectiveness of remedial measures and new construction techniques. Research conducted by Alonso and Alonso (1999) and Lehman (2001) point to instances where new construction techniques considered a priority to reduce collision risk actually *increased* the risk. Research is necessary to resolve these inconsistencies.

There are currently no requirements to report collision fatality in California or the West. The overwhelming majority of collision fatality events go unreported, either because they are undetected or, in some cases, industry fears repercussions from the regulatory community. Therefore, it is extremely difficult to determine the biological significance of collision impacts on a regional or statewide scale without an analysis of data collected broadly in space and time.

Currently, no research is being conducted to address this issue.

Research Needs

1. To focus mitigation efforts and determine the effectiveness of mitigation techniques, monitoring should be included as a research program component, as part of device effectiveness testing and when evaluating newly installed or revised technologies. Monitoring is particularly important along line segments identified as potentially hazardous and other identified high-risk areas. Monitoring standards and success criteria should be established jointly by industry and the regulatory and scientific communities through a consensus-building process designed to achieve general acceptance and concurrence of these standards. Past monitoring methods should be evaluated and guidelines using the best known practices should be established. (See 5.1.6)

5. Goals

The goal of the PIEREA avian collision research is to reduce impacts on birds from collisions with power lines in California, to facilitate the development of environmentally responsible transmission lines and to develop tools and technologies that will considerably reduce mitigation and remediation costs. Mitigating avian power line collisions will also help industry comply with state and federal laws.

The achievement of that goal depends on the ability of researchers to assess the risk to birds from these lines, and to develop effective mitigation. The following research goals are designed to contribute to better understanding and successfully reducing or eliminating avian mortality 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.

The goals developed for the collision subject area are based on the information summary and synthesis developed in previous sections, from discussions with California Energy Commission staff, and from recommendations by members of a Technical Advisory Team that was developed to provide input for this roadmap. This team consisted of representatives from state and federal agencies, electric utilities, avian researchers, and private consultants. For a summary of their responses, see Appendix A.

The PIEREA program recognizes that very little state-specific work has been conducted and disseminated in these areas. Whenever possible, PIEREA will identify existing efforts and form partnerships to leverage resources**.**

Appendix C provides a concise summary of the short-term work outlined below.

5.1 Short-term Objectives[2]

5.1.1 Standardizing Mortality Estimation

A. **Develop a standardized method for estimating collision mortality from dead bird searches and remote sensing technologies. ($50K)**

   Activities needed: (1) Fully evaluate the methods and algorithms employed to estimate mortality. (2) Using the Collision Mortality Assessment section (Section 3.2) of this roadmap as a guide, develop a standardized approach to field estimation of avian collision mortality by measuring and consistently applying bias factors and use-intensity data. (3) Determine the most robust and appropriate method for a given suite of environmental and transmission line characteristics, ensuring that the standards account for typical California scenarios (4) Develop guidelines.

   Critical Factors for Success:
   - Consensus among agency, utility, and regulatory researchers on methods and reporting.

5.1.2 Testing and Documentation of Diversion Device Efficacy ($750K)

A. **Determine the species-specific effectiveness of devices, their durability under varying field conditions, and their application on various transmission line designs in California.**

   Activities needed: (1) Establish a group of leading avian collision researchers to develop a set of metrics to assess the efficacy of diversion devices. (2) Encourage and fund studies designed to evaluate new and existing avian diversion devices, such as Bird Flight Diverters and Spiral Vibration Dampeners, using the metrics established in Activity 1. (2) Expand on the Energy Commission's diverter studies by conducting similar studies throughout the state to determine effectiveness under a variety of field and climatological conditions.

   Critical Factors for Success:
   - Adequate funding to develop trials and controls under a wide range of conditions.

---

[2] 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.

- Participation of utility companies and other transmission line operators.

5.1.3 Test and Document Effectiveness of Remote Collision Detection Devices ($350K)

A. **Expand on the current CEC/EPRI study in North Dakota measuring the effectiveness of Bird Strike Indicator (BSI) and Bird Activity Monitor (BAM).**

Activities needed: (1) Expand upon the results of the EPRI study. (2) Conduct field tests of remote sensing equipment at California sites, and compare study accuracy and costs to field mortality estimation. Ensure that the tests are conducted under a variety of field conditions and with different species groups.

Critical Factors for Success:
- Funding adequate for rigorous and robust study design.
- Participation of utility companies and other transmission line operators.

5.1.4 Determine Collision Risk Levels Associated with Potential High-Avian-Use Habitats ($500K)

A. **Determine collision risk in wildlife habitats known to support concentrated avian use.**

Activities needed: (1) Identify target high-avian-use habitat areas in California (e.g., wetland, riparian, seasonal wetlands, marine and estuarine, ecotones), based on evaluation of wildlife habitat relationship literature and appropriate modeling techniques. (2) Prioritize these areas, based on review and evaluation of the literature. (3) Design studies that incorporate the most recent findings from mortality estimation studies, include control sites, and are sufficiently robust to allow inference to sites with similar characteristics. (4) Conduct studies in the selected areas to document fatality to determine risk levels of lines transecting or paralleling several vegetative communities.

Critical Factors for Success:
- Access and study design consensus and industry cooperation in carrying out the study.
- Industry's reluctance to divulge sensitive information

5.1.5 Determine the Factors Necessary to Develop a Reporting Requirement ($50K)

A. **Perform a scoping study to identify a method for creating a functional reporting requirement for avian collisions with power lines in California.**

Activities needed: (1) Survey members of the electric power industry, regulatory, and research communities to identify the factors that would be necessary to develop an avian collision reporting system that is acceptable to all stakeholders.

Critical Factors for Success:

- Participation by all stakeholders, and a willingness to build a consensus-based process for reporting avian collisions with power lines.

Table 6. Short-term Budget

Objective	Projected Cost ($000)
5.1.1.A Develop or identify a standardized method for estimating collision mortality from dead bird searches and remote sensing technologies.	50
5.1.2.A Determine the species-specific effectiveness of devices, their durability under varying field conditions, and their application on various transmission line designs in California.	750*
5.1.3.A Test and document the effectiveness of remote collision detection devices.	300*
5.1.4.A Determine collision risk in wildlife habitats known to support concentrated avian use.	500*
5.1.5.A Determine the factors necessary to develop an avian collision reporting requirement	50
Total	**1650**

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 Standardizing Mortality Estimation

A. **Refine the standardized mortality estimation method that was developed in the short-term.**

Activities needed: (1) Evaluate the results of mortality studies and field trials to test threshold bias factor values. (2) Revise the collision mortality estimation method based on those evaluations.

5.2.2 Testing and Documentation of Diversion Device Efficacy

A. **I**nclude weather and other environmental variables in studies evaluating the efficacy of diversion devices.

Activities needed: (1) Expand studies as necessary to include a wide variety of environmental variables.

5.2.3 Update the Standard Avian Collision Reference

A. **Develop a process for regular revision of *Mitigating Bird Collisions with Power Lines: The State of the Art in 1994*.**

Activities needed: (1) Create a team of industry, regulatory community, academic, and natural resource agency representatives to develop a process for regularly reviewing, revising, and disseminating this information to resource agencies and industry and incorporating research results. (2) Implement that process as needed to maintain a thorough basis of scientific information for conducting studies and remediating problem transmission lines.

5.2.4 Determine Collision Risk Levels Associated with Potential High-Avian-Use Habitats

A. **Prioritize and focus remediation efforts in areas with the highest documented mortality.**

Activities needed: (1) Evaluate the short-term studies conducted in 5.1.5 to identify areas of the highest documented mortality. (2) Using successful methods and equipment identified in 5.1.2 and 5.1.3, conduct remediation efforts in the high-mortality areas.

5.3 Long-term Objectives

5.3.1 Monitoring

A. **Monitor mitigation effectiveness.**

Activities needed: (1) Monitor the mitigation technologies developed in the short- and mid-term. (2) Based on monitoring results, redesign or discontinue the use of ineffective technologies and support the implementation of the most effective technologies.

5.3.2 Update Standard Avian Collision and Electrocution Reference

B. **Revise the standard reference.**

Activities needed: (1) Based on the document and protocols developed in the short- and mid-term work, update the standard avian collision and electrocution reference to include the most up-to-date research.

6. Leveraging R&D Investments

6.1 Methods of Leveraging

Much of the work identified in this roadmap would be collaborative with other entities; PIEREA would either co-fund projects by other entities, or use outside funds to supportPIEREA efforts.

The questionnaire developed as part of this roadmap (Appendix C) polled industry, the regulatory community, and academia regarding potential funding sources for leveraging research and development funding. Though responses were incomplete, researchers and industry recommended both traditional and new funding sources for research and development activities. Traditional funding sources include EPRI, the Energy Commission, the Edison Electric Institute (EEI), the Avian Power Line Committee (APLIC), and the USFWS.

Many of the sources are currently collaborating on the Audubon National Wildlife Refuge study (Carlton 2001); a model study for estimating collision mortality. New funding sources identified during the questionnaire process include the National Renewable Energy Laboratory (NREL) and the National Wildlife Research Center (NWRC). In addition, funding could be available from all entities that own or operate power lines such as utilities, municipalities, and generators that all benefit from the research.

In California, funding to leverage research and development efforts should incorporate creative partnerships between private and public entities. Consideration of local and regional foundation funding (e.g., National Fish and Wildlife Foundation, Packard Foundation) and private wildlife organizations (e.g., California Waterfowl Association, Ducks Unlimited) in a comprehensive funding strategy could offset the burden traditionally shouldered by industry and the regulatory community for wildlife impact studies. Research funds from California Department of Fish and Game and USFWS are scarce; however, contributions by these agencies could come from staff time and/or compensation funds collected to offset impacts from potential avian collision.

6.2 Opportunities

Co-sponsored efforts are already under way with EPRI. Co-sponsorship opportunities are likely with PG&E, Southern California Edison (SCE), the Western Area Power Administration (WAPA), EPRI, the California Department of Fish and Game (DFG), USFWS, APLIC, and industry groups. No specific collaborative opportunities have been identified; however, each of these organizations is interested in addressing avian collision issues. Based on prior collaboration, the Edison Electric Institute and/or Raptor Research Foundation may be interested in collaborating at some level on the revision of *Mitigating Bird Collisions with Power Lines: The State of the Art in 1994.*

7. Areas Not Addressed by This Roadmap

This roadmap does not address the potential beneficial aspects of transmission lines, or their construction or maintenance.

8. References

(* indicates the inclusion of a reference in the California Energy Commission's *Avian Collision and Electrocution: An Annotated Bibliography*.)

Alonso, J. A., and J. C. Alonso. 1999. Collision of birds with overhead transmission lines in Spain. Pages 57–82 *in:* Birds and Power Lines. Collision, Electrocution and Breeding. M. Ferrer and G.F.E. Janss eds. Servicios Informativos Ambientales/Quercus, Madrid, Spain.

Alonso, J. A., and J. C. Alonso. 1999b. Mitigation of bird collisions with transmission lines through ground wire marking. Pages 113–124 *in:* Birds and Power Lines. Collision, Electrocution and Breeding. M. Ferrer and G.F.E. Janss eds. Servicios Informativos Ambientales/Quercus, Madrid, Spain.

Anderson, A. H. 1933. Electrocution of purple martins. *Condor* 35:204

Anderson, W. L. 1978. Waterfowl collisions with power lines at a coal-fired power plant. *Wildl. Soc. Bull.* 6(2):77–83.

Andersen-Harild, P. and D. Block. 1972. Birds killed by overhead wires in some localities in Denmark. *Dansk Orn. Foren. Tidsskr.* 67:15–23. (English summary).

Anonymous. 1978. Management recommendations—raptors. Unpublished in-house document. California Energy Commission, Sacramento, Calif. 37 pp.

*Anthony, R. G., R. W. Frenzel, F. B. Isaaca, and M. G. Garrett. 1994. Probable causes of nesting failures in Oregon's bald eagle population. *Wildl. Soc. Bull.* 22:576–582.

Archibald, K. 1987. The conservation status of the breeding ground of the red-crowned crane in Hokkaido, Japan. Pages 128–136 *in:* Proceedings of the International Crane Workshop, India. G. W. Archibald and R. F. Pasquier, eds.

Arend, P. H. 1970. The ecological impact of transmission lines on wildlife of San Francisco Bay. Prepared by Wildlife Associates for Pacific Gas and Electric (PG&E). San Ramon, Calif. 24 pp.

Armbruster, M. J. 1990. Characterization of habitat used by whooping cranes during migration. U.S. Fish and Wildlife Service Report 90(4).

Arnold, J. R. 1960. Black rail in San Joaquin Valley of California. *Condor* 62(5):405.

*Austin-Smith, P. J. and G. Rhodenizer. 1983. Ospreys (*Pandion haliaetus*) relocate nests from power poles to substitute sites. *Can. Field-Nat.* 97(3):315–319.

*Avian Power Line Interaction Committee (APLIC). 1994. Mitigating bird collisions with power lines: the state of the art in 1994. Edison Electric Institute/Raptor Research Foundation, Washington, D.C.

Bailey, A. M. 1929. Bird casualties. *Wilson Bull.* 41(2):106–107.

*Baldridge, F. A. 1977. Raptor nesting survey of southern San Diego County, Spring 1977; with an analysis of impacts of powerlines. U.S. Bureau of Land Mngmt. Unpublished report. Riverside, Calif. 29 pp.

Banko, W. E. 1960. The trumpeter swan: its history, habits, and population in the United States. U.S. Fish and Wildlife Service, Washington, D.C. 214 pp.

Banks, R. C. 1979. Human related mortality of birds in the United States. U.S. Fish and Wildlife Service, Washington, D.C. Special Scientific Report: Wildlife No. 215. 16 pp.

Batten, L. A. 1978. The seasonal distribution of recoveries and causes of blackbird mortality. *Bird Study* 25(1):23–31.

Bayle, P. 1999. Preventing birds of prey problems at transmission lines in western Europe (expanded abstract). *Journal of Raptor Res.* 33:43–48.

Beaulaurier, D. L. 1981. Mitigation of bird collisions with transmission lines. Bonneville Power Administration, Portland, Oregon. 83 pp.

Beaulaurier, D. L, B. W. James, P. A. Jackson, J. R. Meyer, and J. M. Lee, Jr. 1982. Mitigating the incidence of bird collisions with transmission lines. Pages 539–550 *in:* Third Annual International Symposium on Environmental Concerns in Rights-of-Way Management, San Diego, Calif., 15–18 February, 1982. State College, Miss.

Benton, A. H. 1954. Relationships of birds to power and communication lines. *Kingbird* 4(3):65–66.

Bevanger, K. 1990. Topographic aspects of transmission wire collision hazards to game birds in the Central Norwegian coniferous forest. *Fauna Norv. Ser. C Cinclus* 13:11–18.

*Bevanger, K. 1993. Hunting mortality versus wire strike mortality of willow grouse (*Lagopus lagopus*) in an upland area of southern Norway. Pages 11-1 to 11-10 *in:*

Proceedings: Avian Interactions with Utility Structures. 1993. Electric Power Research Institute, Palo Alto, Calif.

*Bevanger, K. 1994. Bird interactions with utility structures: collision and electrocution, causes and mitigating measures. *IBIS* 136:412–425.

Bevanger, K. 1999. Estimating bird mortality caused by collision and electrocution with power lines; A review of methodology. Pages 29–56 *in:* Birds and Power Lines. Collision, Electrocution and Breeding. M. Ferrer and G. F. E. Janss eds. Servicios Informativos Ambientales/Quercus, Madrid, Spain.

BioSystems Analysis, Inc. 1990. Wind turbine effects on the activities, habitat, and death rate of birds. Prepared for Alameda, Contra Costa, and Solano Counties, Calif. 2 pp.

Blokpoel, H., and D. R. M. Hatch. 1976. Snow geese, disturbed by aircraft, crash into power lines. *Can. Field Nat.* 90(2):195.

Borell, A. E. 1939. Telephone wires fatal to sage grouse. *Condor* 41(1):85–86.

Boso, B. 1965. Bird casualties at a southeastern Kansas TV tower. *Transactions of the Kansas Academy of Science* 68(1):131–136.

Boyd, H., and M. Ogilvie. 1964. Losses of mute swans in England in the winter of 1962–63. Wildfowl Trust 15th Annual Report:37–39.

Brewer, R. and J. A. Ellis. 1958. An analysis of migrating birds killed at a television tower in east-central Illinois, September 1955–May 1957. *Auk* 75(4):400–414.

Bromby, R. 1981. Killer lines in Colorado present an electrocution hazard for raptors. Colorado Division of Wildlife. *Wildlife News* 6(3).

Brown, L. 1976. British birds of prey: a study of Britain's 24 diurnal raptors. N. N. Collins, London.

Brown, W. M., R. C. Drewien, and E. G. Bizeau. 1985. Mortality of cranes and waterfowl from power line collisions in the San Luis Valley, Colorado. Pages 128–135 *in:* Proceedings of the 4th Crane Workshop, 1985. Platte River Whooping Crane Habitat Management Trust, Grand Island, Neb.

*Brown W. M. 1993. Avian collisions with utility structures: Biological perspectives *in:* Proceedings: Avian Interactions with Utility Structures. 1993. Electric Power Research Institute, Palo Alto, Calif.

*Brown W. M. 1993b. Marking power lines to reduce avian collisions in the San Luis Valley, Colorado *in:* Proceedings: Avian Interactions with Utility Structures. 1993. Electric Power Research Institute, Palo Alto, Calif.

*Brown, W. M. and R. C. Drewien. 1995. Evaluation of two power line markers to reduce crane and waterfowl collision mortality. *Wildl. Soc. Bull.* 23(2):217–227

Byrd, V., J. Sincock, and T. Telfer. 1978. The status of Newell's manx shearwater, a threatened species. Page 80 in: Pacific Seabird Group 5th Annual Meeting, Asilomar, Calif., 13–16 December. Pacific Seabird Group, Stinson Beach, Calif.

Byrne, S. 2000. Bird Strike Monitor. California Energy Commission report P600-00-027. Sacramento, Calif.

*Cade, T. J. 1982. Falcons of the world. Comstock: Cornell University Press.

Carlton, R. G. 2001. Automated systems for monitoring avian interactions with utility structures and evaluating the effectiveness of mitigation measures [Abstract only] *in:* Proceedings from the 2001 Natural Resource Workshop. The leading edge: Meeting environmental challenges for siting and reliability. Edison Electric Institute.

Cassel, J. F., D. W. Kiel, J. J. Knodel, and J. M. Wiehe. 1979. Relation of birds to certain power lines in central North Dakota. North Dakota State University, Fargo. Prepared for the United Power Association, Env. and Lands Div., Elk River, Minn. 50 pp.

Clausen, B. and F. Gudmundsson. 1981. Causes of mortality among free-ranging gyrfalcons in Iceland. *J. Wildl. Dis.* 17(1):105–109.

Cohen, D. A., ed. 1896. California department. *Osprey* 1(1):15.

Colton, H. S. 1945. An unusual accident to a broad-tailed hummingbird. *Plateau* 18(15):15.

Cooper, B. A., R. H. Day, R. J. Ritchie, and C. L. Cranor. 1991. An improved marine radar system for studies of bird migration. *J. Field Ornithol.* 62:367–377.

*Cooper, B. A., T. J. Mabee, and W. M. Brown. 1993. Radar studies of bird movements over power lines in the Monte Vista National Wildlife Refuge, Colorado *in:* Proceedings: Avian Interactions with Utility Structures. 1993. Electric Power Research Institute, Palo Alto, Calif.

Cornwell, G. W. 1968. Needless duck deaths. *Conservation Catalyst* 2(4):15–18

Cornwell, G., and H. A. Hochbaum. 1971. Collisions with wires—a source of anatid mortality. *Wilson Bull.* 83(3):305–306.

Coues, E. 1876. The destruction of birds by telegraph wire. *Am. Nat.* 10(12):734–736.

Council of Europe. 1981. Birds in need of special protection in Europe. Nature and Environment Series No. 24. Strasbourg, France. 154 pp.

Crowder, M. R. and O.E. Rhodes. 2001. Avian collisions with power lines: A review. *In* Avian Interactions with Utility and Communication Structures. Workshop Proceedings . Charleston, S.C. EPRI Technical Report No. 1006907. R. Carlton, Project Manager.

Dawson, B. 1974. Letting them go: great horned owls go to school. *Museum Talk* 49(2):45–48.

Dedon, M., S. Byrne, J. Aycrigg, and P. Hartman. 1990. Bird mortality in relation to the Mare Island 115 k-V transmission line: progress report for 1988/1989. Pacific Gas and Electric (PG&E) Technical and Ecological Services. Prepared for the Department of Navy, Western Division, Naval Facilities Engineering Command, Office of Environmental Management, San Bruno, Calif. Report 443-89.3. 150 pp.

d'Ombrain, A. F. 1945. Migratory birds and overhead wires. *Emu* 45(2):1733–174.

Drager, T. and J. Linthicum, eds. 1985. Peregrine falcon wild nest management, hack sites, and cross-fostering operations. Santa Cruz Predatory Bird Research Group. Univ. of Calif., Santa Cruz.

Drewien, R. 1973. Ecology of Rocky Mountain greater sandhill cranes. Ph.D. diss., Univ. of Idaho, Moscow. 82 pp.

Dunbar, R. J. 1954. Bird mortality—Oak Ridge. *Migrant* 25(4):63–64.

Edison Electric Institute. 2001. The living grid: evolving to meet the power needs of America. Energy Issues/News. www.eei.org/issues/comp_reg/living_grid.pdf.

Elkins, N. 1988. Weather and Bird Behaviour. Illustrated by Crispin Fisher. 2nd ed. T. and A. D. Poyser. Calton, Staffordshire, England.

Ellis, D. H., J. G. Goodwin, Jr., and J. R. Hunt. 1978. Wildlife and electric power transmission *in:* Effects of noise on wildlife. J. L. Fletcher and R. G. Busnel, eds. Academic Press, Inc., New York. 305pp.

Eltringham, S. K. 1963. The British population of mute swan in 1961. *Bird Study* 10(1):10–28.

Emerson, W. O. 1904. Destruction of birds by wires. *Condor* 6(1):37.

Enderson, J. H. and M. N. Kirven. 1979. Peregrine falcon foraging study in the Geysers: Calistoga known geothermal resource area, Sonoma County, Calif. Prepared for the U.S. Bureau of Land Management. Prepared by Department of Biology, Colorado College, Colorado Springs, Colo. 17 pp.

Erickson, W. P., G. D. Johnson, M. D. Strickland. K. J. Sernka, and R. E. Good. 2001. Avian collisions with wind turbines: A summary of existing studies and comparisons to other sources of avian collision mortality in the United States. Western EcoSystems Technology, Inc. Cheyenne, Wyo. 65 pp.

Faanes, C. A. 1987. Bird behavior and mortality in relation to power lines in prairie habitats. U.S. Fish and Wildlife Service. Fish and Wildlife Technical Report 7. 24pp.

Farnham, C. B. Jr. 1971. Snip impaled on cable. *Kingbird* 21(1):10–11.

*Fernandez, C. and J. A. Insausti. 1990. Golden eagles take up territories abandoned by Bonelli's eagles in northern Spain. *J. Raptor Res.* 24(4):124–125.

Ferrer, M. and M. Del La Riva. 1987. Impact of power lines on the population of birds or prey in Doñana National Park and its environment. Mediterranean Birds of Prey III. Natl. Inst. of Game Bio. 12. (English Summary).

Ferrer, M. and M. De La Riva, and J. Castroviejo. 1991. Electrocution of raptors on power lines in southwestern Spain. *J. Field Ornithol.* 62(2):181–190. (English Summary).

Fitzner, R. E. 1975. Owl mortality on fences and utility lines. *Raptor Res.* 9(3/4):55–57.

Flegg, J. J. M. and C. J. Cox. 1975. Mortality in the black-headed gull. *British Birds* 68(11):437–449.

Garzon, A. F. 1977. Birds of Prey in Spain: the present situation. Pp. 159–170 *in:* Proceedings of World Conference on Birds of Prey, R. D. Chancellor, ed. Int. Natl. Council for Bird Pres., Vienna, Austria, 1–3 October, 1975.

*Gauthreaux, S. A., Jr. 1985. Radar, electro-optical, and visual methods of studying bird flight near transmission lines. Prepared by Clemson Univ., Clemson, South Carolina, for the Electric Power Research Institute, Palo Alto, Calif. EPRI EA-4120. 76 pp.

Gerstenberg, R. H. 1972. A study of shorebirds (*Charadrii*) in Humboldt Bay, California, 1968 to 1969. Thesis. Calif. State Univ., Humboldt. 207 pp.

Glue, D.E. 1971. Ringing recovery circumstances of small birds of prey. *Bird Study* 18(3):137–146.

*Glystorff, N. H. 1976. Fugles kollisioner med elledninger (Bird collisions with electric power lines). Arhus University, Denmark. 117 pp.

Goodland Daily News. November 5, 1965. Rare whooping crane is found dead near Atwood. *Goodland Daily News,* Kansas 33(234):1.

Gollop, M. A. 1965. Bird migration collision casualties at Saskatoon. *Blue Jay* 23(1):15–17.

Gosselin, M. 1978. The winter season: Quebec region. *Am. Birds* 32(3):324–326.

Graham, R. 1916. Carolina rail accidentally killed. *Oologist* 33(11):187.

Griepentrog, E. A. 1929. Wire mortalities. *Oologist* 46(2):24.

Hanson, K. E. 1988. Managing transmission lines for wildlife enhancement. *Journal of Arboriculture* 14(12):302–304.

Harrison, J. 1963. Heavy mortality of mute swans from electrocution. Wildfowl Trust 14th Annual Report:164–165.

Hartman, P. A., S. Byrne, and M. F. Dedon. 1992. Bird Mortality in Relation to the Mare Island 115-kV Transmission Line: Final Report 1988–1991. PG&E Technical and Ecological Services Rpt. Number 443-91.3. Prepared for Dept. Of Navy, Western Division, San Bruno, CA.

*Hartman, P. A., S. Byrne, and M. F. Dedon. 1993. Bird Mortality in Relation to the Mare Island 115-kV Transmission Line: Final Report 1988–1991 *in:* Proceedings: Avian Interactions with Utility Structures. 1993. Electric Power Research Institute, Palo Alto, Calif.

Harwin, R. M. 1971. White stork: longevity record. *Ostrich* 42(1):81.

*Haas, D. 1980. Endangerment of our large birds by electrocution: a documentation. *Okol. Vogel* 2:7–57 (English summary).

Heijnis, R. 1976. Ornithological mortality and environmental aspects of above ground high tension wires. *Biological Environmental Research,* The Netherlands. 166 pp.

Heijnis, R. 1980. Vogeltod durch drah tanfluge beihoschspannungsleitungen (Bird mortality from collision with conductors for maximum tension). *Okol. Vogel* (ecol. Birds) 2:111–129.

Hendrickson, J. R. 1949. A hummingbird casualty. *Condor* 51:103.

Herren, H. 1969. The status of the peregrine falcon in Switzerland. Pages 231–238 *in:* Peregrine falcon populations: their biology and decline. J. Hickey. Univ. of Wis. Press, Madison, Wis.

Heye, P. L. 1963. Tower fatalities. *Bluebird* 30(1):7.

Hobbs, J. C. A. and J. A. Ledger. 1986. Powerlines, bird life, and the golden mean. *Fauna and Flora* 44:23–27.

Hodson, N. L. and D. W. Snow. 1965. The road deaths enquiry, 1960–61. *Bird Study* 9:90–99.

*Holberg, R., L. Morrow, S. Lubores, J. Watson, and F. Williams. 1975. Resource and lands investigations program: considerations in evaluating utility line proposals. Mitre Corp., Maclean, Virginia. Prepared for the U.S. Fish and Wildlife Service. Contract No. 08550-CT5-3, Project No, 3500, Dept. W-54.

Holyoak, D. 1971. Movements and mortality of Corvidae. *Bird Study* 16:97–106.

Hoover, K. D. 1978. Introduction. Pages 1–2 *in:* Impacts of transmission lines on birds in flight: proceedings of a workshop. Avery, M. L., ed. 1978. Oak Ridge Associated Universities, Oak Ridge, Tennessee. 31 January–2 February, 1978. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-78/48. 151 pp.

*Houston, C. S. 1978. Recoveries of Saskatchewan-banded great horned owls. *Can. Field-Nat.* 92(1):61–66.

Howe, M. A. 1989. Migration of radio-marked whooping cranes from the Arkansas-Wood Buffalo population: patterns of habitat use, behavior, and survival. U.S. Fish and Wildlife Service, Patuxtent Wildlife Research Center, Laurel, Maryland. Tech. Rpt. 21. 33 pp.

*Hugie, R. D., J. M. Bridges, B. S. Chanson, and M. Skougard. 1993. Results of a Post-Construction Bird Monitoring Study on the Great Falls-Conrad 230-kV Transmission Line *in:* Proceedings: Avian Interactions with Utility Structures. 1993. Electric Power Research Institute, Palo Alto, Calif.

James, B. W. and B. A. Haak. 1979. Factors affecting avian flight behavior and collision mortality at transmission lines. Final Report. Bonneville Power Administration, Portland, Oregon. 106 pp.

Jarvis, M. J. F. 1974. High tension power lines as a hazard to larger birds. *Ostrich* 45:262.

Jennings, A. R. 1961. An analysis of 1,000 deaths in wild birds. *Bird Study* 8(1):25–31.

Kaiser, G. W. and R. McKelvey. 1978. Destruction of birds by man-made objects. Unpub. manuscript *cited in:* Avian mortality at man-made structures: an annotated bibliography (revised). U.S. Fish and Wildlife Service, Biological Services Program, National Power Plant Team, FWS/OBS-80/54. 152 pp.

Krapu, G. L. 1974. Avian mortality from collisions with overhead wires in North Dakota. *Prairie Nat.* 6(1):1–6.

Kretzschmar, H. 1970. Wiederum: Grosstrappe gegen Starkstromleitung. *Falke* 16:94–95 (German).

La Berge, W. E. 1976. Waterfowl power line collisions. Illinois Natural History Survey Rpt. No. 160 (October):2–3.

Lano, A. 1927. Great blue heron (Ardea herodias) electrocuted. *Auk* 44(2):246.

Ledger, J. A., J. C. A. Hobbs, and T. V. Smith. 1993. Avian interactions with utility structures: southern Africa experiences. Pages 4-1 to 4-11 *in:* Proceedings: Avian Interactions with Utility Structures. 1993. Electric Power Research Institute, Palo Alto, Calif.

Lee, J. M. 1978. Effects of transmission lines on bird flights: studies of Bonneville Power Administration lines. Pages 53–68 *in:* Impacts of transmission lines on birds in flight: proceedings of a workshop. M.L. Avery, ed. 1978. Oak Ridge Associated Universities, Oak Ridge, Tennessee. 31 January–2 February, 1978. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-78/48. 151 pp.

Lehman, R. N. 2001. Raptor electrocutions on power lines: current issues and outlook. *Wildl. Soc. Bull.* 29 (5): 804–813.

Lemmon, W. P. 1898. Virginia rail killed by striking a telephone wire. *Auk* 15(1):51.

Lewis, J. C. 1974. Ecology of the sandhill crane in the southeastern flyway. Ph.D. thesis. Oklahoma State Univ., Stillwater. 214 pp.

Malcolm, J. M. 1982. Bird collisions with a power transmission line and their relation to botulism at a Montana wetland. *Wildl. Soc. Bull.* 10:297–304.

*Manville A. M. II. 1999. The ABC's of avoiding bird collisions at communication towers: The next steps [abstract only] *in:* Avian interactions with utility structures; proceedings of the December 1999 workshop. 1999. Electric Power Research Institute, Palo Alto, Calif.

*Marion, W. R. and R. A. Ryder. 1975. Perch site preferences of four diurnal raptors in northeastern Colorado. *Condor* 42:166.

Mathiasson, S. 1999. Swans and electrical wires, mainly in Sweden. Pages 83–111 *in:* Birds and power lines; collision, electrocution and breeding. M. Ferrer and G. F. E. Janss eds. Servicios Informativos Ambientales/Quercus, Madrid, Spain.

McCann, K. 2001. Eskom?Ewt Partnership: The wattled crane marking project in South Africa. *In* Avian Interactions with Utility and Communication Structures. Workshop Proceedings . Charleston, S.C. EPRI Technical Report No. 1006907. R. Carlton, Project Manager.

McDonald, J. N. 1979. Waterfowl collisions with utility wires: two observations on the southern plains. *Texas Journal of Science* 31(4):369–370.

McGlauchlin, D. C. 1977. Description and chronology of events on Snake Creek embankment. In-house report for the Audubon Wildlife Refuge, Coleharbor, North Dakota. 9 pp.

McKenna, M. G. and G. E. Allard. 1976. Avian mortality from wire collisions. *North Dakota Outdoors* 39(5):16-18.

McNeil, R., J. R. Rodriguez, and H. Quellet. 1985. Bird mortality at a power transmission line in northeastern Venezuela. *Biol. Conserv.* 31:153–165.

Mead, C. J. 1979. Mortality and causes of death in British sand martins. *Bird Study* 26(2):107–112.

Meyer, J. R. 1978. Effects of transmission lines on bird flight behavior and collision mortality. Bonneville Power Administration, Engineering and Construction Division, Portland, Oregon. 200 pp.

Meyer, J. R. and J. M. Lee. 1979. Effects of transmission lines on flight behavior of waterfowl and other birds. Second symposium on environmental concerns in rights-of-way management, University of Michigan, Ann Arbor, 16–18 October 1979.

*Miller, A. D. 1993. The engineering perspective of power line marking systems to reduce avian collisions *in:* Proceedings: Avian Interactions with Utility Structures. 1993. Electric Power Research Institute, Palo Alto, Calif.

Moorehead, M. and L. Epstein. 1985. Regulation of small scale energy facilities in Oregon: background report. Volume 2. Oregon Dept. of Energy, Salem.

*Morkill, A. E. and S. H. Anderson. 1993. Effectiveness of yellow aviation balls in reducing sandhill crane collisions with power lines *in:* Proceedings: Avian Interactions with Utility Structures. 1993. Electric Power Research Institute, Palo Alto, Calif.

Murarka, I. P., J. G. Ferrante, E. W. Daniels, and E. E. Pentecost. 1976. An evaluation of environmental data relating to nuclear power plant sites: Prairie Island nuclear generating plant site. Division of Environmental Impact Studies, Argonne National Laboratory, Argonne, Ill. ANL/EIS-6. 54 pp.

National Oceanic and Atmospheric Administration. 2001. Map of isokeraunic zones of the United States. www.nssl.noaa.gov/researchitems/lightning.shtml.

Nesbitt, S. A. and D. T. Gilbert. 1976. Power lines and fences: hazards to birds. *Florida Naturalist* 49(2):23.

Newton, I. 1979. Population ecology of raptors. Buteo Books, Vermillion, S. Dak. 399 pp.

NUS Corp. 1979. Impacts of overhead wires on birds: a review. Unpublished report. Prepared for the Electric Power Research Institute, Palo Alto, Calif. 47 pp.

Ogilivie, M. A. 1967. Population changes and mortality of the mute swan in Britain. Wildfowl Trust 18th Annual Report: 64–73

Olendorff, R. R. and R. N. Lehman. 1986. Raptor collisions with utility lines: an analysis using subjective field observations, final report. Prepared by U.S. Bureau of Land Management. Prepared for Pacific Gas and Electric Company, San Ramon, Calif. 73 pp.

Olsen, J. and P. Olsen. 1980. Alleviating the impact of human disturbance on the breeding peregrine falcon II: public and recreational lands. *Corella* 4(3):54–57.

Olsson, V. 1958. Dispersal, migration, longevity, and death causes of *Strix aluco, Buteo buteo, Ardea cinerea. Acta Vertebratica* 1(2):91–189.

Owen, M. and C. J. Cadbury. 1975. The ecology and mortality of swans at the Ouse Washes, England. *Wildfowl* 26:31–42.

Pangburn, C. 1945. Extraordinary fatality of a blue-winged teal. *Auk* 62(1):142.

*Pearson, D.C. 1993. Avifauna Collision Study in the San Jacinto Valley of Southern California *in:* Proceedings: Avian Interactions with Utility Structures. 1993. Electric Power Research Institute, Palo Alto, Calif.

*Pendleton, E. 1978. To save raptors from electrocution. *Defenders* 53:18–21.

Perdeck, A. C. and G. Speek. 1984. A radar study of the influence of expected ground speed, cloudiness, and temperature on diurnal migration intensity. *Ardea* 72:189–198.

Perrins, C. M. and C. M. Reynolds. 1967. A preliminary study of the mute swan, *Cygnus olor.* Wildfowl Trust 18th Annual Report: 74–84.

Peterson, R. L. and B. P. Glass. 1946. Notes on bird mortality during nocturnal thunderstorms near College Station, Texas. *Condor* 48(2):95–96.

*Platt, J. B. 1976. Bald eagles wintering in Utah desert. *Am. Birds* 30:783–788.

Pogson, T. H. and S. M. Lindstedt. 1988. Abundance, distribution, and habitat of Central Valley population greater sandhill cranes during winter. Biology and Wildlife, Univ. of Alaska, Fairbanks.

Pomeroy, D. E. 1978. The biology of Marabou storks in Uganda, II: breeding biology and general review. *Ardea* 66(1-2):1–23.

Potter, J. K. and J. J. Murray. 1949. Fall migration: middle Atlantic coast region. Audubon Field Notes 3(1):8–10.

Quigley, E. 1977. Utility line siting and wetland preservation. Dissertation. University of Wisconsin, Madison. 231 pp.

Quortrup, E. R. and J. E. Shillinger. 1941. 3,000 wild bird autopsies on wild lake areas. *Journal of the Vet. Med. Assoc.* 99:382–387.

Rasmussen, P. J. 2001. Problem resolutions for avian interactions at two NSP facilities. *In* Avian Interactions with Utility and Communication Structures. Workshop Proceedings . Charleston, S.C. EPRI Technical Report No. 1006907. R. Carlton, Project Manager.

Rees, M. D. 1989. Andean condors released in experiment to aid the California condor. *End. Species Tech. Bull.* XIV(1/2):8–9.

Reigel, M. and W. Winkel. 1971. On death causes of white storks (*C. ciconia*) according to ringing recovery reports. *Vogelwarte* 26(1):128–135. (English summary).

Rennsen, T. A. et al. 1975. Vogelsterfte in Nederland tengevolge van aanvaringen met hoogspanningslijnen. Rijksinstitut voor naturbeheer. 65 pp. (Cited in Glystorff 1976, not seen).

Rix, C. E. 1970. Birds of the northern territory. *South Australian Ornith.* 25(6):147–191.

Russell Daily News. 1968. Rare whooping crane found near reservoir. *Russell Daily News,* Kansas. April 16, 1968. Page 1.

Rusz, P. J., H. H. Price, R. D. Rusz, and G. A. Dawson. 1986. Bird collisions with transmission lines near a power plant cooling pond. *Wildl. Soc. Bull.* 14:441–444.

Sanderson, G. C. and W. L. Anderson. 1981. Waterfowl studies at Lake Sangchris, 1973–1977. *Ill. Nat. History Survey Bull.* 32 (article 4):656–689.

Schorger, A. W. 1952. Ducks killed during a storm at Hot Springs, South Dakota. *Wilson Bull.* 64(2):113–114.

Schroeder, C. H. 1977. Geese hit power transmission line. *North Dakota Outdoors* 40(2):inside cover.

Scott, W. E. 1950. Report on the convention at Two Rivers. *Passenger Pigeon* 12(2):69–72.

Scott, R. E., L. J. Roberts, and C. J. Cadbury. 1972. Bird deaths from power lines at Dungeness. *British Birds* 65(7):273–286.

Scott, J. M. and R. M. Jurek. 1985. Report to the California Fish and Game Commission on condor mortality issues, actions, and recommendations. U.S. Fish and Wildlife Service and Calif. Dept. of Fish and Game. 45 pp.

Scott, P. and The Wildfowl Trust. 1972. The swans. Houghton Mifflin Company, Boston. 242 pp.

*Serr, E. M. 1976. The spring migration: northern Great Plains. *Am. Birds* 30:855–858.

Siegfried, W.R. 1972. Ruddy ducks colliding with wires. *Wilson Bull.* 84(4):486–487.

Sisson, J. 1975. Death trap. *National Wildlife* 13(2):18.

*Smith, J. C. 1985. Perching and roosting patterns of raptors on power transmission towers in southeast Idaho and southwest Wyoming. *J. Raptor Res.* 19(4):135–138.

Smith, J. R. and J. T. Schletz. 1991. Bird/power line collision detection system. Prepared for Pacific Gas and Electric (PG&E), San Ramon, Calif. Report 009.4-91.10 25 pp.

*Smith, J. R., 1993. Bird/powerline collision detection system *in:* Proceedings: Avian Interactions with Utility Structures. 1993. Electric Power Research Institute, Palo Alto, Calif.

*Smith, J. Q. and D. K. Voigts. 1993. Bird casualties at a Crystal River, Florida power plant 1982–1986. Pages 19-1 to 19-10 *in:* Proceedings: Avian Interactions with Utility Structures. 1993. Electric Power Research Institute, Palo Alto, Calif.

Snow, C. 1973. Habitat management series for unique or endangered species, Rpt. No. 7: Golden eagle, *Aquila chrysaetos.* U.S. Bureau of Land Management Tech. Note T-N-239. 52 pp.

Somerset, H. 1972. Jabiru killed by power line. *South Australian Ornith.* 26(3):55

Stahlecker, D. W. 1975. Impacts of a 230-kV transmission line on Great Plains wildlife. Thesis. Colorado State Univ., Fort Collins. 67 pp.

*Steenhof, K. and J. M. Brown. 1978. Management of wintering bald eagles. Eastern Energy and Land Use team, Water Resources Analysis Office (formerly National Stream Alteration Team), U.S. Fish and Wildlife Service, FWS/OBS-78/79. 59 pp.

*Steenhof, K., M. N. Kochert, and J. A. Roppe. 1993. Nesting by raptors and common ravens on electrical transmission line towers. *J. Wildl. Manage.* 57(2):271–281.

*Stewart, P. A. 1969. Movements, population fluctuations, and mortality among great horned owls. *Wilson Bull.* 3:19–27.

Stout, I. J. 1967. The nature and pattern of non-hunting mortality in fledged North American waterfowl. Thesis. Virginia Polytech. Inst., Blackburg. 329 pp.

Stout, I. J. and G.W. Cornwell. 1976. Non-hunting mortality of fledged North American waterfowl. *J. Wildl. Manage.* 40(4): 681–693.

Tacha, T. C., D. C. Martin, and C. G. Endicott. 1978. Mortality of sandhill cranes associated with utility highlines in Texas. Pages 175–176 *in:* Proceedings of 2nd annual crane workshop, J. C. Lewis, ed. Rockport, Texas. Natl. Audubon Society. Colorado State University Printing Service, Ft. Collins, Colorado.

Thomas, C. B. 1977. The mortality of Yorkshire Canada Geese. *Wildfowl* 28(1):35–47.

Thompson, L. S. 1978. Transmission line wire strikes: Mitigation through engineering design and habitat modification *in:* Impacts of transmission lines on birds in flight: proceedings of a workshop. Avery, M. L., ed. 1978. Oak Ridge Associated Universities, Oak Ridge, Tennessee. 31 January–2 February, 1978. U.S. Fish and Wildlife Service, Biological Services Program. FWS/OBS-78/48. 151 pp.

Trauger, D. L., A. Dzubin, and J. P. Ryder. 1971. White geese intermediate between Ross' geese and lesser snow geese. *Auk* 88(4):856–875.

U.S. Fish and Wildlife Service. 1978. U.S. Fish and Wildlife Service position regarding overhead power and communication lines. 4pp.

Vian, W. E. 1971. The wintering bald eagle (*Haliaeetus leucocephalus*) on the Platte River in southcentral Nebraska. M.S. thesis. Kearney State College, Kearney, Neb. 60 pp.

Walker, A. 1916. Some raptores [sic] of Douglas County, South Dakota. *Condor* 18(3):130.

Walkinshaw, L. H. 1956. Sandhill cranes killed by flying into power line. *Wilson Bull.* 68(4):325–326.

Weaver, D. K. and R. St. Ores. 1974. Trumpeter swan mortality. Pages 86–89 *in:* Proceedings and Papers of the Trumpeter Swan Society Conference, Martin, South Dakota, 18–20 September 1973.

Weir, D. N. 1971. Mortality of hawks and owls in Speyside. *Bird Study* 18(3):147–154.

Welty, J. C. 1972. The life of birds. Alfred A. Knopf, New York. 546 pp.

Weston, F. M. 1966. Bird casualties on the Pensacola Bay Bridge (1938–1949). *Florida Naturalist* 39(2):53–54.

Wheeler, R. H. 1966. Sandhill crane casualties in the blizzard of March 22, 1966. *Nebraska Bird Review* 34(4):69–70.

Wiese, J. H. 1979. A study of the reproductive biology of herons, egrets, and ibis nesting on Pea Patch Island, Delaware: final interpretive report. Delmarva Power and Light Company, Wilmington, Delaware. 255 pp.

Willdan Associates. 1982. Impact of the Ashe-Slatt 500-kV transmission line on birds at Crow Butte Island: post-construction final report. Prepared by Willdan Associates, Portland, Oregon. Prepared by Bonneville Power Administration, Portland, Oregon. 155 pp.

Willard, D. E., J. T. Harris, and M. J. Jaeger. 1977. The impact of a proposed 500-kV transmission route on waterfowl and other birds. Oregon Public Utility Commission, Salem, Oregon. 89 pp.

Willard, D. E. and B. J. Willard 1978. The interaction between some human obstacles and birds. *Environ. Manage.* 2(4):331–340.

Williams, R. D., and E. W. Colson. 1989. Raptor associations with linear rights-of-way. Pages 173–192 *in:* Western raptor management symposium and workshop, B. G. Pendleton, ed. Boise, Idaho, 1987. National Wildlife Federation Scientific and Technical Series #12.

Wilmore, S. B. 1974. Swans of the world. Taplinger Publishing, New York.

Yarris, G. S. 2001. Letter to Marcus Yee of the California Energy Commission dated December 8, 2001. California Waterfowl Association. Sacramento, Calif.

Zimmerman, D. R. 1976. The bald eagle bicentennial blues. *Nat. Hist.* 85:8–16.

Personal Communications

Steve Clay, Fish and Wildlife Service, Modoc NWR. May 31, 2002

Hesters, Mark. California Energy Commission. June 12, 2001

Gary Ivey, Wetland and Wildlife Consultant. May 31, 2002

McCuen, Al. California Energy Commission. 2001

Spiegel, Linda. California Energy Commission. Numerous conversations, 2001 and 2002.

Appendix A
PIER Roadmap Questionnaire and List of Recipients

Questions

1. Are you currently, or do you plan to begin, a research project related to this issue?
2. If so, could you briefly describe the research? If your research is in advanced stages, what are your significant findings? What is your primary funding source?
3. What do you think is the most critical research currently underway? (Include who is doing the research).
4. What do you think are the most important research topics for California (list topics, include other)?
5. What research should be accomplished in the near term (1-3 yrs), mid-term (4-6 years) and long-term (10 years)?
6. Please list potential sources of co-funding.
7. What are the most promising techniques for reducing collisions with transmission lines?
8. Are you aware of any current studies being conducted to test these techniques?
9. Do see any value in developing a monitor to detect bird strikes on wires?
10. Bird mortality studies estimate mortality from wire strikes using direct counts adjusted to account for search, habitat, scavenger removal and crippling bias. What bias factors do think should or shouldn't be used?

Questionnaire Recipients

California Energy Commission
PG&E
EPRI
Point Reyes Bird Observatory
EDM International, Inc.
Southern California Edison
BioResource Consultants
USDA/APHIS/NWRC
Western Area Power Administration
Colson and Associates
PacifiCorp
USFWS
WEST, Inc.

Appendix B
Current Status of Programs

This section outlines those efforts that most closely address the avian collision issue and its impact on California. As noted throughout the roadmap, little research is being conducted to address avian collision issues at this time.

Current Status: California

California Energy Commission

- The Public Interest Energy Research, Environmental Area (PIEREA) is working with the Electric Power Research Institute (EPRI) to develop and field-test two automated line monitors: the Bird Strike Indicator (BSI, for detecting strikes) and the Bird Activity Monitor (BAM, for measuring flight intensity). The study includes a quantitative and replicable method for estimating fatality. Future research will determine the feasibility and efficacy of the BSI and BAM systems, so that each system may used most effectively.
- The Energy Commission is co-funding a study at the Audubon National Wildlife refuge in North Dakota that is examining the effectiveness of selected avian diversion devices, under a narrow set of environmental conditions and relative to diverting cranes.
- The Energy Commission is working Pacific Gas and Electric, The Nature Conservancy, CSU Sacramento, and a private land owner to field test diversion devices at a preserve in northern California where sandhill crane collisions are being reported.

Current Status: Regional and National

Avian Power Line Interaction Committee (APLIC)

- The Avian Power Line Interaction Committee (APLIC) is sponsored by the Edison Electric Institute, and members include representatives from government agencies and electric utilities. The 1994 APLIC publication, *Mitigating Bird Collisions with Power Lines: The State of the Art in 1994,* has become the standard reference for researchers and regulators focusing on causes and effects of avian power line collisions. APLIC conducts periodic workshops and training of field personnel to improve awareness of collision problems and discuss current research.

Appendix C

Short-term Avian Collision Roadmap Research Goal Summary

Title	*Description*	*Potential Stakeholders*	*Success Factors*	*Est. Cost*	*Potential Cost-sharing*
Standardizing Mortality Estimation	Using the Collision Mortality Assessment section of this roadmap as a guide, develop a standardized approach to field estimation of avian collision mortality by measuring and consistently applying bias factors and use intensity data.	PG&E, SCE, WAPA, EPRI, DFG, USFWS, APLIC	Consensus among agency, utility, and regulatory researchers on methods and reporting	$50,000	PG&E, SCE, Industry
Testing and Documentation of Diversion Device Efficacy	Using the Collision Mortality Assessment section of this roadmap as a guide, design and conduct field experiments to determine the efficacy of avian diversion devices (Bird Flight Diverters [BFD], Spiral Vibration Dampeners [SVD], etc.) under a variety of field and climatological conditions.	PG&E, SCE, WAPA, EPRI, DFG, USFWS, APLIC	Adequate funding to develop trials and controls under a wide range of conditions; transmission line operator participation.	$750,000	PG&E, SCE, Industry
Test and Document Effectiveness of Remote Collision Detection Devices	Expand on a current study being conducted by EPRI to measure the effectiveness of Bird Strike Indicator (BSI) and Bird Activity Monitor (BAM) remote sensing equipment and compare study accuracy and costs to field mortality estimates.	PG&E, SCE, WAPA	Funding adequate for rigorous and robust study design; transmission line operator participation.	$300,000	Industry, USFWS, DFG
Determine Collision Risk Levels Associated with Potential High-Avian-Use Habitats	High collision risk has been documented for transmission lines that transect or parallel wetlands, but little is known of the collision risk of lines transecting other potential high avian use vegetative communities (e.g., riparian and estuarine). Conduct field studies to determine risk levels of lines transecting or paralleling several vegetative communities.	PG&E, SCE, WAPA, EPRI, APLIC, Industry	Access and study design consensus and industry cooperation in carrying out the study (See text).	$500,000	Industry, USFWS, DFG
Determine the Factors Necessary to Develop a Reporting Requirement	California lacks a requirement for reporting avian collisions with power lines. Engage all stakeholders to develop a consensus-based reporting requirement that facilitates open data exchange for the purpose of developing and implementing effective mitigation strategies and technologies.	State regulatory agencies, PG&E, SCE, WAPA, EPRI, EEI, APLIC, Industry	Participation in a consensus-based process for developing a reporting requirement.	$50,000	PG&E, SCE, Industry