ENERGY RELATED ENVIRONMENTAL RESEARCH

A Roadmap for PIER Research on Avian Power Line Electrocution in California

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Executive Summary

The California Energy Commission's Public Interest Energy Research Program (PIER) Environmental Subject Area (PIEREA) is dedicated to developing cost effective approaches to evaluate and resolve environmental impacts of energy generation, transmission, and use. Electrocutions from distribution systems are causing thousands of bird deaths annually and recent studies suggest that the problem is not being satisfactorily resolved. In addition to bird deaths, electrocutions can result in power outages that are estimated to cost the California economy a billion annually from lost productivity and repairs. The purpose of this roadmap is to summarize what is known about avian electrocution from past and current research and to identify and prioritize research needs on the issue, particularly as it pertains to California. The roadmap also suggests collaborative opportunities to leverage research and development efforts in a manner that benefits all stakeholders, including utilities, regulatory agencies, and wildlife protection groups. The successful completion of short-, mid-, and long-term goals suggested in this document will help industry comply with state and federal laws, improve electrical system reliability, and protect the state's valuable natural resources.

Avian fatalities from electrocution was first documented in the United States in the early 1920's and continued to increase with the proliferation of electrical power distribution systems. Electrocution hazards are almost entirely limited to distribution systems (<69 kilovolts [kV]) where energized phase-to-phase, or energized phase to conductor distances are less than the skin-to-skin distance in birds. Due to their relatively large body size and, in some species, frequent use of distribution poles for hunting, raptors are a particularly susceptible group. Among raptor species, golden eagles (*Aquila chrysaetos*) are especially vulnerable due to a series of factors which cumulatively increase electrocution hazard to population-effect levels.

Factors influencing electrocution risk can be divided into two categories: 1) biological factors which consider raptor morphology, behavior, life history, habitat use, and distribution, and 2) physical factors which include weather, geography, pole design, system configuration and other attributes of the physical setting affecting power distribution. Past research in these areas has focused on risk assessment of biological and physical factors and suggests key attributes contributing to increased risk.

Weather increases electrocution risk in several ways. Wind generally decreases raptor flight navigation and landing precision increasing exposure to hazards. Precipitation wets feathers, which increase feather conductivity, and storm events often promote "still hunting" from distribution poles increasing the duration of hazard exposure. Precipitation may also alter prey availability patterns resulting in a shift in hunting patterns possibly introducing new electrocution hazards.

Landscape physiognomy (the pattern of vegetative communities and land uses surrounding electrical distribution systems) may also contribute to higher electrocution risk. Flat terrain through grasslands or, for some species, through agricultural lands where natural perches are a limiting factor may promote use power poles. The habitat matrix in the vicinity of distribution systems will affect prey abundance that directly influences raptor use and local population levels. These factors may increase the duration and intensity of exposure to hazardous conditions.

Characteristics and design of distribution and transmission lines are the variables most influencing electrocution risk. Particularly hazardous designs have been identified worldwide, but the degree of risk and the relationship between these designs and other contributing factors are not well understood. In general, single phase, top conductor and 3 phase, single arm pole designs are hazardous to raptors and other species. The consistent causal mechanism in electrocution from these designs is the distance between energized phases (or ground structures and energized phases) being within the skin-to-skin contact distance of large birds. European and African pole designs vary but are, in some cases, extreme hazards for the same reason.

Biological factors affecting electrocution risk and addressed in this report include age, sex and behavior (including tower nesting). Review of available literature clearly demonstrates that young birds (both juveniles and subadults) are far more susceptible to electrocution than adults. Young birds typically lack the refined flight and landing skills of adults and more readily collide with, or contact, hazardous structures. Young birds may also select different habitats than adults and, if these habitat types support hazardous distribution systems, may be exposed to higher electrocution risk.

Tower nesting is well documented in the literature and, under certain conditions, may be used as a management tool to mitigate the loss of nesting substrate or increase local productivity. Both benefits and detriments of towers as nesting substrates for raptors have been identified. The obvious benefit of a secure platform essentially free of terrestrial predators and offering excellent vantage of the surrounding terrain may be offset by decreased productivity, exposure to Electro-Magnetic Field (EMF) radiation, and exposure to electrocution hazards. Additional research is required to fully understand the relative benefits of tower nesting.

Electrocution risk reduction and elimination has taken the form of both mitigating these impacts and by modifying the design of new structures. Mitigation often consists of remediation of hazardous structures identified during maintenance activities or brought to a utilities attention by any number of sources. Remediation or design modification is usually pole type-specific and often pole retrofit is accomplished assuming measures suitable for a given type will remediate a problem on any like hazardous structure. However, emerging research has demonstrated monitoring is essential in determining a measures efficacy under a variety of environmental and physical conditions.

To further refine future research needs, a questionnaire was developed and distributed to an Avian Electrocution Advisory Team. Responses were summarized and synthesized into the short and long-term research area recommendations.

Although California supports among the highest bird diversity in North America, information specific to avian electrocution in the state is lacking due to poor reporting requirements and data dissemination. Despite the lack of reported electrocutions, the potential for a widespread and significant electrocution problem in California is very real. California is host to 618 bird species, of which 23 are diurnal and 14 are nocturnal raptors. Of these, 15 diurnal and 6 nocturnal species have wingspans or body sizes sufficient to present an electrocution risk. California's coast and Central Valley are known migratory paths for fall and spring raptor movements and support thousands of over-wintering migrants often concentrating birds in urban areas that support dense electrical distribution systems. Given the vast network of distribution systems throughout the state, the probability of electrocutions in high bird use areas is quite high. Retrofitting the entire system is cost-prohibitive and unnecessary. However, developing systematic methods for identifying high-risk situations, remedial tools, and monitoring requirements could significantly reduce and/or avoid electrocutions. Additionally, all stakeholders must work together to exchange information and implement statewide solutions.

In the short-term (1–3 years) this roadmap recommends that the following objectives be addressed: (an asterick indicates a high probability that funding will be leveraged)

Objective	**Projected Cost ($000)**
• Develop or identify a standardized method for estimating electrocution mortality.	50
• Determine the relative electrocution risks associated with various pole and distribution structure designs	200*
• Begin or expand research and development efforts focusing on modified and new structure and remediation device designs	1,000
• Develop a risk assessment model	75
• Develop and support updated APLIC training courses	200
• Develop a standardized method for monitoring pole lines to determine electrocution mortality rates and electrocution events.	45
• Support the revision of *Suggested Practices for Raptor Protection on Power Lines: The State of the Art in 1996.*	50*
• Develop bird safe construction guidelines suitable for CPUC adoption	50
• Commission a scoping study to document policy needs and potential impediments to implementing a reporting policy	45*
• Research and Create a Clearinghouse for Data and Information Relating to Avian Electrocution.	50
Total	**$1,765**

The PIEREA Avian Electrocution Roadmap also identifies mid-term (3–10 year) and long-term (10–20 year) goals, some of which build on the short-term work listed above.

Roadmap Organization

This roadmap 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 work addressing avian electrocution issues. *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 electrocution research that the proposed activities do not address. *Appendix A: Current Status of Programs* offers an overview of work being done to address avian electrocution issues. *Appendix B: PIER Roadmap Questionnaire and List of Recipients* lists the questions developed for an advisory team that was assembled to review avian electrocution from power line issues and indicates questionnaire recipients. *Appendix C: Short-term Avian Electrocution Roadmap Research Goals Summary* is a synopsis of the recommended short-term research, potential stakeholders, success factors, estimated costs, and potential cost-sharing entities.

1. Issue Statement

Power structure-related avian electrocutions have likely resulted in hundreds of thousands of bird fatalities annually and numerous power outages in California. There is a need for methods and tools to determine the statewide extent of avian electrocutions from power structures and to reduce and / or prevent these electrocutions.

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 the *Roadmap for PIER Research on Avian Power line Electrocution 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 electrocution with power structures.

This roadmap focuses on this issue because research conducted in other states and countries suggests that in California, there are probably hundreds of thousands of avian deaths annually due to electrocution. Nearly all of these deaths involve protected raptors. Additionally, bird electrocutions can cause power outages. Approximately 10 percent of all outages in the state are caused by wildlife and bird-caused outages are the third leading cause of all outages in Pacific Gas and Electric's territory (Dedon pers comm, Colson, pers. comm). Results of a survey of 560 electric utilities in the United States by Southern Engineering Company revealed that animals are the third most important identifiable cause of all power outages and birds cause more outages than any other wildlife group (Harness 1998 in Kruger 2001a). A recent report estimated that power outages and power quality disturbances cost the California economy between $13.2 and $20.4 billion annually (CEIDS 2001). Therefore, power outages caused by electrocutions potentially result in economic losses approaching $1 billion annually.

Data on the statewide significance of electrocution are lacking due, in part, to utilities reluctance to report fatalities because of the specter of legal repercussions and potential negative publicity. Despite the widespread belief that retrofitting and other remediation measures had effectively reduced avian electrocutions, recent research indicates the problem still exists and may, in fact, be worse than once thought. While some devices have been designed to insulate power structures, many are ineffective, degrade quickly in the field, or have actually increased electrocution risk. Characteristics of pole configurations that pose the greatest electrocution risk are still being determined and little has been done to date to proactively retrofit problem poles. Moreover, bird safe construction standards for new pole construction are not required in California.

Given the vast network of distribution lines in California (~200,00 miles and 4.2 million poles) and avian diversity (39 raptor, 47 seabird, 63 shorebird, 48 duck and goose, 42 gull and tern, and 12 heron and egret species; all of which are at risk for electrocution), the incidence of avian electrocution is likely quite high. This risk will increase with increased demand for new lines from new developments requiring energy delivery. Addressing the issue will help determine and develop new technologies necessary to reduce or prevent risk; there is no reason to doubt that the development (and application) of durable, reliable, cost effective devices and stricter building requirements could not resolve the issue.

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 the magnitude and rates (mortality) of electrocution. Standardization will allow meaningful comparison of study results and aid in identification of particularly hazardous designs or areas. Second, research should be directed towards comparison of the relative risk of various pole designs used in California. This work would build on the recommendations in *Suggested Practices for Raptor Protection on Power Lines: The State of the Art in 1996* (APLIC 1996) and focus testing to pole designs in California. Third, research should focus on reducing electrocution risk. This would include testing the effectiveness of existing remediation devices and developing new devices. Fourth, research should focus on developing a process for thorough assessment of existing distribution systems towards prioritizing retrofit activities. Current funding for these activities should be focused on poles or pole lines exhibiting the highest electrocution risk. Integral to the success of this research need is training of electrical utility employees to recognize and document hazardous pole designs. This research need could be accomplished through expansion of the existing training series development by APLIC. Fifth, research should supported development of a comprehensive and practical method for monitoring electrocution rates both in areas identified as hazardous and in response to retrofit and remediation efforts. Pole design features and retrofit methods remain largely untested and there is growing evidence that current practices may be ineffective or, in some cases, actually increase electrocution risk. Sixth, the Avian Power Line Interaction Committee's (APLIC) *Suggested Practices for Raptor Protection on Power Lines: The State of the Art in 1996* should be revised to include research that has been conducted since its publication. As a standard reference document for industry, researchers, and the regulatory communities, the revision of this document would ensure a comprehensive and current information source forming a common ground for decisions regarding mitigation and remediation. This research need should include development of "bird safe" guidelines in a form similar to the California Public Utility Commission's (CPUC) General Order No. 95 which could supplement this

Order requiring construction standards and practices that ensure minimal risk. Finally, there is a need for improved data and information dissemination. For several reasons, there is a real lack of published information relating to avian electrocution in California. The final goals of this roadmap are to develop a system-wide reporting requirement and promote publication of methods and techniques to address the problem by establishing a clearinghouse for information and data on the issue.

Public benefits from this program include increased reliability in energy transmission, reduction in bird fatalities and, in some cases, reduction in 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 is a major goal of this research program. 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 electrocution fatalities and associated population declines. Results could be immediately applied to support identification of high-risk electrocution and application of 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

The Avian Powerline Interaction Committee's (APLIC) 1996 report[1] on power line electrocution in the United States states that avian electrocution risk is highest along distribution lines (generally less than 69 kV) where the distance between energized phases, ground wires, transformers and other components of an electrical distribution system are less than the length or skin-to-skin contact distance of birds. The distance between energized components along transmission lines (> 69 kV) is generally insufficient to present avian electrocution risk. However, some transmission lines, especially in Europe and some Africa, are an electrocution hazard by design because larger birds are capable of spanning the distance between these structures (Janns and Ferrer 1999).

[1] Avian Powerline Interaction Committee (APLIC). 1996. *Suggested Practices for Raptor Protection on Power Lines: The State of the Art in 1996.* Edison Electric Institute/Raptor Research Foundation. Washington, D.C..

As a group, raptors are particularly vulnerable to electrocution because of their relatively long wingspans (APLIC 1996); their habit of using distribution poles as perches, roosts, sunning areas, and for still hunting (Nelson and Nelson 1976); and exposure from use of poles and pole complexes for nesting (see Melquist and Johnson (1974). Factors affecting the degree of electrocution risk among birds are discussed later in this chapter.

Avian power line electrocution was first documented in 1922 (Hallinan 1922) in Jacksonville, Florida, although it has undoubtedly occurred since the construction of the first power lines in the mid-1800s. The literature offers occasional documentation of electrocution between 1922 and 1971 (see Marshall 1940 and Dickinson 1957), when 11 bald (*Haliaeetus leucocephalus*) and four golden (*Aquila chrysaetos*) eagles were discovered electrocuted in Jackson Canyon, Wyoming (Olendorff 1981). In the decades following this discovery, observations of avian electrocution increased resulting in the documentation of 90 species electrocuted worldwide, with 30 species documented in North America and 14 species documented in California (Table 1).

Table 1. Summary of Bird Species Electrocution

Species	***Location***	***Description***	***Source***
9 species	So. San Diego County	Sunderset nuclear power transmission line	Baldridge, F.A. 1977
Egyptian Goose *Alopochen aegyptiacus*	South Africa	Transmission	Van Rooyen and Ledger 1999
California Condor *Gymnogyps californianus*	California	Unknown	Jurek 1994
Andean Condor *Vultur gryphus*	California	Unknown	Rees 1989
Turkey Vulture *Cathartes aura*	United States	Distribution lines	Harness 1996, Williams and Colson 1989
Osprey *Pandion haliaetus*	Idaho, Montana, Minnesota; Canada, France	Transmission and distribution lines; 25-kV distribution line	Bayle 1999, Vanderburgh 1993, Harmata 1991, Benson 1980, Peacock 1980, Dunstan 1968
Honey Buzzard *Pernis apivoris*	Germany, France	Distribution lines	Bayle 1999
African Fish-Eagle *Haliaeetus vocifer*	South Africa	Distribution	Kruger 2001b
Bald Eagle *Haliaeetus leucocephalus*	California, Colorado, Idaho, Missouri, North Dakota, Oregon, South Dakota, Texas, Utah, Wisconsin, Wyoming	Transmission and distribution lines	Williams and Colson 1989, Frenzel 1984, Peacock 1980, Baglien 1975, Boeker and Nickerson 1975, Olendorff 1972, Smith and Murphy 1972, Kingery 1971
Black Kite *Milvus migrans*	France, Germany, Spain	Unknown	Bayle 1999, Janns and Ferrer 1999, Haas 1993
Red Kite *Milvus milvus*	Doñana National Park, Spain; France, Germany	16-kV transmission lines with pylon terminations	Haas 1993, Ferrer et al. 1991
Bearded Vulture *Gypaetus barbatus*	France	Unknown	Bayle 1999
Black-shouldered Kite *Elanus caeruleus*	South Africa	Transmission	Van Rooyen and Ledger 1999
Egyptian Vulture	Doñana National Park, Spain;	16-kV transmission lines	Janns and Ferrer 1999, Ferrer et al.

Table 1. Summary of Bird Species Electrocution

Species	***Location***	***Description***	***Source***
Neophron percnopterus	Sudan	with pylon terminations	1991, Nickolaus 1984
Eurasian Griffon *Gyps fulvus*	Doñana National Park, Spain; France	16-kV transmission lines with pylon terminations; Unknown	Bayle 1999, Ferrer et al. 1991
Cape Griffons (Vultures) *Gyps coprotheres*	South Africa	Unknown	Ledger and Hobbs 1999, Ledger and Annegarn 1981, Jarvis 1974, Markus 1972
European Black Vulture *Aegypius monachus*	Spain	Unknown	Bayle 1999
African White-backed Vulture *Psuedogyps africanus*	South Africa	Transmission	Van Rooyen and Ledger 1999
Lappet-faced Vultures *Torgos tracheliotus*	Sudan, South Africa	Unknown	Nickolaus 1984, Kruger 2001b
Short-toed Snake Eagle *Circaetus gallicus*	Doñana National Park, Spain; France	16-kV transmission lines with pylon terminations	Bayle 1999, Janns and Ferrer 1999, Ferrer et al. 1991
Black-breasted Snake Eagle *Ciraetus pectoralis*	South Africa	Transmission	Kruger 2001b
Brown Snake Eagle *Circaetus cinereus*	South Africa	Transmission	Van Rooyen and Ledger 1999
Western Marsh-harrier *Circus aeruginosus*	France, Germany, Spain	Unknown	Bayle 1999
Hen Harrier *Circus cyaneus*	France, Germany, Spain, United States	Unknown	Bayle 1999, Williams and Colson 1989
Pale Chanting Goshawk *Melierax canorus*	South Africa	Unknown	Kruger 2001b
European Sparrowhawk *Accipiter nisus*	France	Unknown	Bayle 1999
Cooper's Hawk *Accipiter cooperi*	Montana	Distribution lines	O'Neil 1988
Goshawk *Accipiter gentilis*	Montana; France, Germany, Spain	Distribution lines	Bayle 1999, Ferrer et al. 1991, O'Neil 1988
Common Black Hawk *Buteogallus anthracinus*	Arizona	Distribution line	Schnell 1980
Harris's Hawk *Parabuteo unicinctus*	Arizona	Distribution lines and transformers	Dawson 1995
Buteo sp.	Switzerland	17-kV distribution line	Bijlveld and Goeldin 1976
Swainson's Hawk *Buteo swainsoni*	Montana, Utah, California United States	Distribution lines	Williams and Colson 1989, O'Neil 1988, Bloom , pers com 2002
Jackal Buzzard *Buteo rufofuscus*	South Africa	Transmission	Van Rooyen and Ledger 1999
Red-shouldered Hawk *Buteo lineatus*	California	Distribution line	Bloom (pers. Comm.)
Red-tailed Hawk *Buteo jamaicensis*	California, Colorado, Idaho, Missouri, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Texas, Utah, Wisconsin, Wyoming, United States; Canada, Mexico	Distribution lines	Harness 2001a, Thelander 1999, Williams and Colson 1989, O'Neil 1988, EPRI 1982, Peacock 1980, Ellis et al. 1978, Switzer 1977, Boeker and Nickerson 1975,
Eurasian Buzzard	Doñana National Park, Spain;	16-kV transmission lines	Bayle 1999, Janns and Ferrer 1999,

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Species	***Location***	***Description***	***Source***
Buteo buteo	France, Germany	with pylon terminations	Haas 1993, Ferrer et al. 1991
Ferruginuos Hawk *Buteo regalis*	California, Colorado, Idaho, Nevada, New Mexico, Utah, Wyoming; Western United States, Canada, Mexico	Transmission and distribution lines	Harness 2001a, Thelander 1999, Williams and Colson 1989, EPRI 1982, Gretz 1981, Peacock 1980, Switzer 1977
Rough-legged Hawk *Buteo lagopus*	California, Idaho, Nevada, New Mexico, Oregon, Utah, Wyoming; Western United States, Canada, Germany,	Transmission and distribution lines	Bayle 1999, Thelander 1999, Williams and Colson 1989, EPRI 1982, Peacock 1980, Ellis et al. 1978, Switzer 1977
Black Eagle *Ictinaetus malayensis*	South Africa	Unknown	Kruger 2001b
Spanish Imperial Eagle *Aquila adalberti*	Doñana National Park, Spain	16-kV transmission lines with pylon terminations	Ferrer et al. 1991
Golden Eagle *Aquila chrysaetos*	Colorado, California, Idaho, Kansas, Missouri, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Texas, Utah, Washington, Wyoming; Canada, France, Germany, Mexico, Spain.	Transmission and distribution lines	Harness 2001a, Thelander 1999, Bayle 1999, Colson 1989, O'Neil 1988, USFWS 1988, EPRI 1982, Bromby 1981, Gretz 1981, Peacock 1980, Ellis et al. 1978, Nelson and Nelson 1977, Switzer 1977, Baglien 1975, Beecham and Kochert 1975, Boeker and Nickerson 1975, Laycock 1973, Williams and Snow 1973, Olendorff 1972, Smith and Murphy 1972, Kingery 1971
Verreaux's (Black) Eagle *Aquila verreauxii*	South Africa	Distribution lines	Ledger et al. 1993
Tawny Eagle *Aquila rapax*	South Africa	Transmission	Van Rooyen and Ledger 1999
Steppe Eagle *Aquila nipalensis*	South Africa	Transmission	Kruger 2001b
Bonelli's Eagle *Hieraetus fasciatus*	Doñana National Park, Spain; France, and Spain	16-kV transmission lines with pylon terminations	Janns and Ferrer 1999, Real and Mañosa 1997, Ferrer et al. 1991, Fernandez and Insuasti 1990
African Hawk Eagle *Hieraaetus spilogaster*	South Africa	Distribution lines	Kruger 2001b
Booted Eagle *Hieraetus pennatus*	Doñana National Park, Spain; France	16-kV transmission lines with pylon terminations	Bayle 1999, Ferrer et al. 1991
Martial Eagle *Polemaetus bellicosus*	South Africa	Unknown	Ledger et al. 1993, Dean 1975
Lanner Falcon *Falco biarmicus*	South Africa	Distribution	Kriger 2001b
Peregrine Falcon *Falco peregrinus*	Doñana National Park, Spain; Germany, South Africa	16-kV transmission lines with pylon terminations	Haas 1993, Ferrer et al. 1991, Kruger 2001b
Prairie Falcon *Falco mexicanus*	Idaho, Nevada, New Mexico, Utah, Wyoming	Distribution lines	EPRI 1982
Merlin *Falco columbarius*	France, Western United States	Distribution lines	Bayle 1999, Williams and Colson 1989
Hobby *Falco subbuteo*	Germany, Spain, France	Unknown	Bayle 1999, Haas 1993
European Kestrel *Falco tinnunculus*	Doñana National Park, Spain; France, and Germany	16-kV transmission lines with pylon terminations	Bayle 1999, Janns and Ferrer 1999, Haas 1993, Ferrer et al. 1991
Greater Kestrel	South Africa	Transmission	Van Rooyen and Ledger 1999

Table 1. Summary of Bird Species Electrocution

Species	*Location*	*Description*	*Source*
Falco rupicoloides			
American Kestrel *Falco sparverius*	Utah, Western United States	Distribution lines	Williams and Colson 1989, Ellis et al. 1978
Helmeted Guineafowl *Numida meleagris*	South Africa	Transmission	Van Rooyen and Ledger 1999
Wood Stork *Leptoptilos crumeniferus*	Uganda, Africa	Unknown	Pomeroy 1978
White Stork *Ciconia ciconia*	South Africa, Spain	Transmission	Janss and Ferrer 1999, Van Rooyen and Ledger 1999
Black Stork *Ciconia nigra*	Spain	Transmission	Janss and Ferrer 1999
Cattle Egret *Bubulcus ibis*	Spain	Transmission	Janss and Ferrer 1999
Heron *Ardea cinerea*	New Mexico, Nevada, Utah, Wyoming; Germany, Spain	Distribution lines	Janns and Ferrer 1999, Haas 1993, Benson 1981
Blackheaded Heron *Ardea menalocephala*	South Africa	Transmission	Van Rooyen and Ledger 1999
Great Blue Heron *Ardea herodias*	Arkansas, Montana	Distribution lines	O'Neil 1988, Lano 1927
Grey-crowned Crane *Balearica regulorum*	South Africa	Transmission	Van Rooyen and Ledger 1999
Barn Owl *Tyto alba*	Doñana National Park, Spain; France, Germany, South Africa	16-kV transmission lines with pylon terminations	Bayle 1999, Janns and Ferrer 1999, Van Rooyen and Ledger 1999, Haas 1993, Ferrer et al. 1991
Eastern Screech Owl *Otus asio*	Eastern United States	Distribution lines	Harness 1996
Western Screech Owl *Otus kennicottii*	Western United States	Distribution lines	Williams and Colson 1989
Great Horned Owl *Bubo virginianus*	California Colorado, Idaho, Kansas, Michigan, Missouri, Montana, Nevada, New Mexico, North Dakota, Pennsylvania, Utah, West Virginia, Wyoming; Canada	Distribution lines	Frank and Lutz 1997, Houston and Francis 1993, O'Neil 1988, EPRI 1982, Peacock 1980, Ellis et al. 1978, Gillard 1977, Pearson et al 2001, Switzer 1977, Boeker and Nickerson 1975, Brady 1969
Eurasian Eagle Owl *Bubo bubo*	France, Germany, Spain	Unknown	Bayle 1999, Haas 1980
Cape Eagle Owl *Bubo capensis*	South Africa	Unknown	Kruger 2001b
Spotted eagle Owl *Bubo africanus*	South Africa	Transmission	Van Rooyen and Ledger 1999
Giant Eagle Owl *Bubo lacteus*	South Africa	Unknown	Kruger 2001b
Snowy Owl *Nyctea scandiaca*	Western U.S.	Distribution lines	Williams and Colson 1989
Little Owl *Athene noctua*	Doñana National Park, Spain; France, Germany	16-kV transmission lines with pylon terminations	Bayle 1999, Haas 1993, Ferrer et al. 1991
Burrowing Owl *Speotyto cunicularis*	Western United States	Distribution lines	Williams and Colson 1989
Tawny Owl *Strix aluco*	Doñana National Park, Spain; France, Germany	16-kV transmission lines with pylon terminations	Bayle 1999, Janns and Ferrer 1999, Ferrer et al. 1991
Barred Owl *Strix varia*	Western United States	Distribution lines	Williams and Colson 1989

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Species	***Location***	***Description***	***Source***
Great Gray Owl *Strix nebulosa*	Idaho	Unknown	Harness 1996
Long-eared Owl *Asio otus*	Idaho; Germany	Unknown	APLIC 1996, Haas 1993
Short-eared Owl *Asio flammeus*	Utah; France	Unknown	Bayle 1999, Benson 1977
Marsh Owl *Asio capensis*	South Africa	Transmission	Kruger 2001b
Northern Saw-whet Owl *Aegolius acadicus*	Western United States	Distribution lines	Williams and Colson 1989
Boreal Owl *Aegolius funereus*	Western United States	Distribution lines	Williams and Colson 1989
Mute Swan *Cygnus olor*	United Kingdom	Distribution line	Scott et al. 1972, Harrison 1963
Wood Pigeon *Columba palumbus*	Spain	Transmission	Janss and Ferrer 1999
Great Spotted Woodpecker *Dendrocopos major*	Spain	Transmission	Janss and Ferrer 1999
Green Woodpecker *Picus viridis*	Spain	Transmission	Janss and Ferrer 1999
Lesser Black-backed Gull *Larus fuscus*	Spain	Transmission	Janss and Ferrer 1999
Gulls *Larus sp.*	North Carolina	Transmission lines	Dickinson 1957
Raven *Corvus corvus*	California, Montana, Nevada, New Mexico, Oregon, Utah, Wyoming; Mexico, Spain	Distribution lines	Harness 2001a, Janns and Ferrer 1999, O'Neil 1988, Pearson et al, 2001, EPRI 1982
Jackdaw *Corvus monedula*	Spain	Transmission	Janss and Ferrer 1999
Black Crow *Corvus capensis*	South Africa	Transmission	Van Rooyen and Ledger 1999
Pied Crow *Corvus albus*	South Africa	Transmission	Van Rooyen and Ledger 1999
Azure-winged Magpie *Cyanopica cyanus*	Spain	Transmission	Janss and Ferrer 1999
Magpie *Pica pica*	Spain	Transmission	Janss and Ferrer 1999
Loggerhead Shrike *Lanius ludovicanius*	Florida	13-kV distribution line	Hallinan 1922
Rose-ringed Parakeet *Psittacula krameri*	India	Distribution line	Dilger 1954
Purple Martin *Progne subis*	Arizona	Distribution line	Anderson 1933
Spotless Starling *Sturnus unicolor*	Spain	Distribution line	Janns and Ferrer 1999
Stonechat *Saxicola torquata*	Spain	Distribution line	Janns and Ferrer 1999

Because many electrocutions go undocumented, far more species have been affected by electrocution than have been reported in the literature. There are about two hundred thousand miles of distribution lines in the state, and 21 species of raptors with wingspan lengths within the range of concern. The Central Valley has a particularly abundant raptor population during the winter months. EPRI (1982) and Dedon (1999) estimate that up to 25 percent of all outages are caused by birds and many electrocutions do not result in outages. While it was once thought that the issue of avian electrocution was largely resolved (APLIC 1994), recent studies show that the problem is persisting and far worse than originally thought (Lehman 2001, Harness pers comm.). Devices designed to insulate structures or prevent raptor use of poles have been problematic, and in some cases, have exacerbated the problem. Clearly there is a need for research activities to evaluate the extent of avian electrocution in the state and to develop tools and technologies needed to reduce and resolve this issue.

3.1 Reported Fatalities

The extent of avian electrocutions is unknown mainly because most fatalities go unreported or undetected. A few authors have attempted to determine the extent of raptor electrocution fatalities from information related to band recoveries and from autopsies conducted in wildlife disease laboratories. Although band recovery information can be a valuable tool in determining sources of fatalities across large geographic areas or relatively long time periods, the percent of band recoveries is low (generally < 1%) and cause of death is not always accurately determined (Houston and Francis 1993, APLIC 1996, Houston et al. 1998). Therefore, numbers of electrocution deaths is greatly underestimated.

In some cases, researchers attempted to determine cause of death and gain a sense of fatalities through conducting mail surveys (e.g., Blue 1996, Olendorf et al 1981). However, these efforts were designed to sample industry and the regulatory community and, as acknowledged by the authors, were incomplete and did not represent a thorough or systematic survey of knowledgeable sources.

The National Wildlife Health Laboratory (1985) reported that 9.1 percent (130 of 1429) of dead bald eagles examined between 1963 and 1984 and collected from throughout the United States (but primarily in the southeast) died of electrocution. Similarly, Franson et al (1995) reported on the examination of more than 4,300 bald and golden eagles submitted to the laboratory from throughout the United States between the mid-1960s and early 1990s. Electrocution accounted for 25 percent of golden and 12 percent of bald eagle fatalities submitted during that time period. Franson et al. (1995) postulated that the increased frequency of golden eagle electrocutions, compared to bald eagle electrocutions, might be attributed to golden eagle use of power poles as perches or for still hunting.

Reported fatality data nationwide, as part of a comprehensive study of impacts of pesticide use and application on wildlife spanning the period 1960 to 1974, indicate 4% of eagle fatalities were from electrocution (Coon et al 1970, Mulhern et al 1970, Belisle et al 1972, Cromartie et al 1975, Prouty et al 1977). The nationwide sample of eagles in this study was biased towards birds received from the southeastern United States (closest to the laboratory) and therefore may not accurately portray nationwide electrocution mortality.

A more recent study by Harness and Wilson (2001) tallied reported raptor electrocutions in the western United States by species and related these data to pole and structure types. Reports obtained from private and public utilities revealed that 748 of 1,428 (52 percent) confirmed electrocutions were eagles and that golden eagles were electrocuted 2.3 times more frequently than bald eagles. Buteos (*Buteo sp.)* were the next most frequent group in which electrocutions were reported.

3.2 Factors Affecting Electrocution Fatality

Factors contributing to electrocution risk can be divided into two groups; physical factors (e.g., weather, pole, and power line characteristics) and biological factors (e.g., physical characteristics of birds, habitat use). Examination of how these factors interrelate and how they individually and cumulatively contribute to electrocution risk is important in understanding the electrocution problem and its possible solutions.

3.2.1 Physical Factors Affecting Electrocution

Weather. Weather-related factors that have been demonstrated to increase electrocution risk include precipitation, wind, and relative humidity. Wind, especially gusty winds, may push birds into power lines and structures that would otherwise be low risk. Furthermore, wind may hamper a bird's ability to affect a smooth landing, exposing wings and feet to hazardous conditions. Anderson (1975), EPRI (1982), and Benson (1980) found that about twice as many raptors were electrocuted on poles with cross-arms perpendicular to prevailing winds than on those with cross-arms that were parallel or diagonal to the prevailing winds. Negotiating a smooth landing during windy conditions is apparently much easier when the cross-arm perch is presented perpendicular to the birds landing approach.

Electrocutions can be more frequent in winter when rain and/or snow causes feather wetting and substantially increases the risk of electrocution due to increased conductivity and some loss of maneuverability (Nelson and Nelson 1977). Carcass counts from 24 five-mile stretches of distribution lines in Idaho, Oregon, Nevada, Utah, New Mexico, and Wyoming revealed that 80.6 percent of all golden eagle electrocutions occurred during winter, presumably because of the exacerbating effects of precipitation and an increase in still hunting behavior which results in more frequent pole use (Benson 1980). The effect of "grounding" (i.e., increasing the area of potential conductivity between ground structures and energized phases) was also noted by Hamerstrom et al. (1974) who observed increased electrocution risk after heavy, wet snowstorms. Increased conductivity from salt or electrolytic rain or snow may increase electrocution hazard (for example around Salt Lake City [Hallinan 1922]). Ferrer et al (1987) noted that precipitation and relative humidity increased the conductivity of feathers and otherwise less conductive body parts thereby increasing raptor electrocution risk along power lines in Doñana National Park, Spain.

Physiognomic Factors. Physiognomic factors affecting electrocution risk include the geographic location and direction of a transmission line in relation to the habitat types and vegetative characteristics of the surrounding landscape. Simply stated, electrocution risk is influenced by how and when birds use the habitat and habitat features in the vicinity of the line.

Vegetative community types and quality in the vicinity of power lines (and, on a larger scale, the landscape physiognomy of the region) affect prey population levels, visibility and hunting vantage, prey availability, and a number of other extrinsic raptor population factors. Although hazardous pole and power distribution designs will always present an electrocution risk, physiognomic factors that increase avian use or concentrate birds in the vicinity of hazardous poles can greatly increase this risk and create a population-level affect. For example, Woodbridge and Garrett (1993) noted that high prey abundance may be a contributing factor to increased electrocution risk by sustaining locally high raptor populations and exposing more birds to problem poles. APLIC (1996) noted that high prey abundance was associated with a diverse habitat matrix.

Based on the number of reported electrocutions of species occupying specific habitat types, Switzer (1977) noted the number of reported electrocutions in relation to habitat type and concluded that forest-dwelling birds are less likely to be electrocuted than grassland, shrubland or "parkland" species. Benson (1980) noted that natural perches such as snags, trees, and stumps are abundant in forested habitats and serve to reduce the frequency with which raptors use power lines for perching in these habitats. Furthermore, species of the genus *Accipiter* (e.g., goshawk, Cooper's hawk) are more reclusive and generally forage and nest within the understory of forested habitats, also reducing the frequency of power pole use. Similarly, ground nesting and roosting species like the northern harrier and short-eared owl are less susceptible to electrocution because of infrequent use of power poles (APLIC 1996). Finally, O'Neil (1980) reported more frequent electrocutions in grassland habitats than in less diverse agricultural lands but found no difference in raptor electrocution frequency between hilly and flat terrain, although his study did not consider prey abundance factors.

Ferrer and Harte (1997) determined that dispersing young Spanish imperial eagles (*Aquila adalberti*), a species suffering population declines primarily due to electrocution, were selecting agricultural land, a land use which required a large network of power lines. The authors suggested retrofitting dangerous poles in agricultural lands as an action necessary for population recovery.

Distribution Line Characteristics. Avian and raptor electrocution risk stems from the design of poles and related electrical distribution structures. Designs that provide adequate spacing between conducting phases and between conductors and energized structures present no electrocution risk to birds. APLIC (1996) provides an excellent overview of typical transmission and distribution line designs and characteristics of these structures that can present a hazard to birds. The following summary is based on this document and, where cited, Olendorff (1981) and other literature.

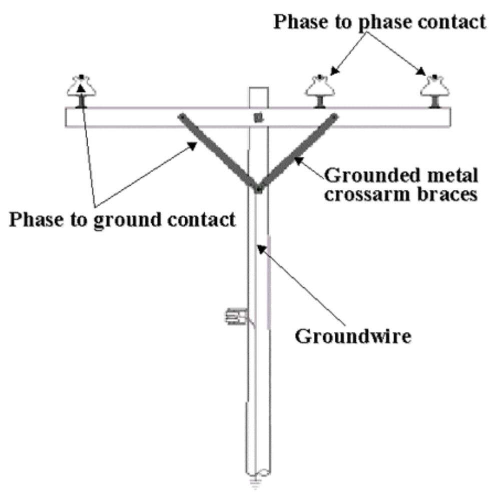

Figure 1: Typical distribution pole showing energized and grounded components

Electrocution is largely a distribution line system problem because spacing between conducting phases and between conductors and ground structures on distribution systems are within the wingspan or flesh-to-flesh distance of birds (Figure 1). Spacing between conducting phases or these phases and ground structures on transmission lines is usually 2.1 to 9.1 meters (7 to 30 feet) which is well outside the wingspan and body lengths of birds. The same metrics on distribution lines are typically 0.6 to 1.8 meters (2 to 6 feet) and often less on terminal or corner poles or poles supporting transformers, jumper lines, or related energized structures (Figure 2).

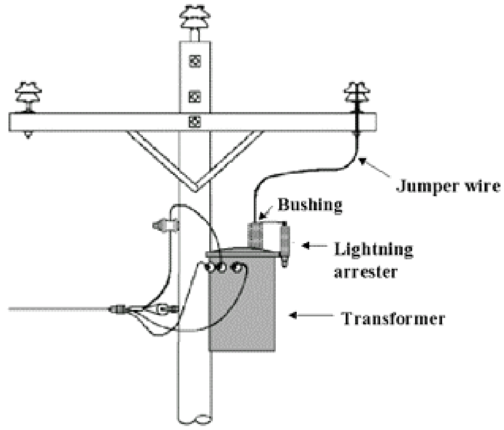

Figure 2: Three phase conductor with transformer showing energized components

Hazardous design configurations include poles supporting single- or three-phase lines in which the distance between 1) conductors or energized components of the distribution system (phase to phase) or 2) ground wire and/or bonded structures and conductors or energized components of the distribution system are less than the flesh-to-flesh distance of birds coming into contact with the system (phase to ground). Certain pole and configurations designs, many of which are common in California, have been demonstrated as particularly hazardous to birds (Table 2). Evidence of the hazard of selected designs and configurations are provided in the literature and summarized below.

Table 2. Summary of Power Line and Pole Designs Identified as Electrocution Hazards

Pole/Line Design Type	*Description of Hazardous Features*	*Source*
Single-phase with top phase conductor	Insufficient space between ground wire extending to top of pole and energized conductor	Olendorff 1981
Single-phase with crossarm and top ground wire	Insufficient space between ground wire and grounding structures and energized conductor	Olendorff 1981
Three-phase with crossarm supporting conductors and ground wire extending to braces for bonding purposes	Insufficient space between energized conductors and between conductors and bonded grounding structures	Harness 1996, Olendorff 1981
Three-phase with crossarm supporting conductors (compact design)	Insufficient spacing between energized phases	Olendorff 1981
Steel three-phase with crossarm supporting conductors with jumper wires over top of crossarm	Insufficient space between energized conductors and between conductors and bonded grounding structures	Ferrer et al. 1991
Three-phase dual crossarm with steel bayonet lightning rod	Insufficient space between energized conductors and between conductors and bonded grounding structures	Olendorff 1981
Three-phase with dual perpendicular crossarms and exposed jumpers (corner pole design)	Insufficient space between exposed jumpers, between jumpers and conductors, and between jumpers/conductors and bonded grounding structures	Olendorff 1981
Three-phase 69-kV horizontal post design	Insufficient space between energized conductors on insulators and grounding structures	Olendorff 1981
Three-phase “wishbone” design with and without under build	Insufficient space between energized conductors and between conductors and bonded grounding structures	Olendorff 1981
South African “Kite” design	Insufficient space between ground wire and grounding structures and energized conductor	Janns and Ferrer 1999, Ferrer et al. 1991
Single- or three-phase transformer bank design	Insufficient space between energized conductors, between conductors and grounding structures, and between jumpers, lightning arresters, and exposed bushings and grounding structure	Olendorff 1981

Table 2. Summary of Power Line and Pole Designs Identified as Electrocution Hazards

Pole/Line Design Type	*Description of Hazardous Features*	*Source*
Three-phase pole-top, offset and staggered switching configurations	Insufficient space between energized conductors and between conductors and bonded grounding structures	APLIC 1996

Smith and Nelson (1976) filmed golden eagles approaching power lines in an attempt to determine which factors contributed to hazardous conditions. They found that inadequate spacing between phases was the primary cause of eagle electrocution and recommended a minimum 43-inch spacing between all phases and between phases and ground structures. Similarly, Goodwin (1975) noted the lack of electrocution hazard on transmission lines that had adequate spacing between energized phases. Early research by Nelson and Nelson (1977) indicated that golden eagle electrocution was attributable almost exclusively to single pole, cross-arm type construction with insufficient conductor spacing. The authors added that 95 percent of these electrocutions could be prevented by correcting two percent of the poles. A later evaluation by O'Neil (1980 found that 61 percent of 61 recovered raptors were electrocuted by poles with double-arm construction or on poles with a transformer.

In an analysis of prey remains and fatality frequency under 3,120 power poles operated by the Moon Lake Electric Association in Colorado, Harness (1999a) determined that dead end or tap terminations and poles with transformer banks accounted for 78 percent of mortalities. The remaining fatalities were associated with tangent poles (poles arranged in a linear fashion without transformer, corner, or intersection features).

In a comprehensive study of raptor electrocution mortality in Doñana National Park, Spain, Ferrer et al. (1991), found that a pylon-type pole design with a terminal conductor and exposed loop of wire passing through the pylon caused a majority of raptor fatalities.

Electrocution was a hazard to ospreys (*Pandion haliaetus*) nesting along a 25-kV distribution line in Manitoba, Canada (Vanderburgh 1993). Braces and platforms extending above the three-phase line accommodated the nesting ospreys, which accepted the nesting sites, and reduced, but did not eliminate, the electrocution hazard.

Frank and Lutz (1997), in a study of great horned owl productivity and habitat use, documented the electrocution of all three recently fledged young in the only case of three fledglings from the same nest documented during the study. Although the authors did not provide details of the mortalities, the loss of all fledglings from a single site suggests a particularly hazardous pole near the nest site.

The most current research with respect to high-risk pole types involved a survey of 58 rural electric utilities in 17 western states and Canada, designed to solicit information on the extent and causes of raptor electrocution (Harness and Wilson 2001). The study, in which researchers aggressively contacted Rural Utility Service (formerly Rural

Electrification Administration), municipal, investor-owned, state, and federal utilities, resulted in 520 responses from 15 western states and Canada in which electrocution could be verified as a cause of fatality, and a particular pole design was identified. Fifty-three percent of electrocutions were attributed to poles with transformers, whereas 14 percent and 13 percent, respectively, were attributed to three-phase dead-end and three-phase tangent structures. (See APLIC 1996 for a discussion of pole and hardware types.)

Based on the information provided above, many different pole designs pose some level of risk to raptors and other large birds. Based on the work of O'Neil (1980), Harness (1999a), and Harness and Wilson (2001), poles with transformers present the greatest electrocution risk followed by terminal and tangent design poles. The current challenge for researchers is determining which poles present the greatest threat and under which conditions poles are particularly hazardous. Ranking structures and hazardous conditions in this manner will facilitate removal or remediation of the most hazardous poles and designs, efficiently reducing electrocution risk.

3.2.2 Biological Factors Affecting Electrocution

Biological factors contributing to an electrocution risk include the morphological attributes of birds, bird metrics, life history attributes, and bird behavior. As previously discussed, raptors are most susceptible to electrocution, because of their large body size, frequent use of poles for various purposes, and certain behaviors which expose them to increased risk. This section of the report summarizes literature relating to these factors.

Behavior. Bird behavior may influence electrocution risk in several ways. Raptors, in particular, frequently use poles and power lines as perches for hunting, sunning, roosting, and nesting. Frequent use of distribution line structures results in more frequent contact with potentially hazardous designs and, therefore, increases electrocution risk. Landing approach to a pole or line varies among raptor species and may introduce increased electrocution risk.

Use of power poles for "still-hunting" has been documented in prairie falcons (*Falco mexicanus*), red-tailed hawks (*Buteo jamaicensis*), American kestrels (*Falco sparverius*), golden eagles, (Dunstan et al 1978) and gyrfalcons (*Falco rusticolus*) (White and Weeden 1966) and likely most other medium and large raptors utilizing a perch and wait hunting strategy (Bloom, pers. Comm.). Dunstan et al (1978) found that still-hunting from fixed objects (often power poles) was the "major search method" for golden eagles in this study. This behavior lends itself to increased pole use, in areas where poles are the most suitable perch structure, and, as a result, increases electrocution risk in larger species with wingspans or body lengths capable of spanning the distance between energized structures (e.g., golden eagles, red-tailed hawks).

Raptors that regularly engage in still-hunting often selecting poles that impart some hunting advantage. Poles providing exceptional vantage points over proven hunting grounds or pole perches in areas of high prey concentrations are often selected more frequently than other pole locations. However, EPRI (1982) concluded there was no statistical correlation between pole height and frequency of electrocution except that poles that provided the best view over the widest terrain area (height above surrounding terrain instead absolute pole height) were used more frequently and therefore presented a greater electrocution risk than other pole locations (also see Boeker and Nickerson 1975, Nelson and Nelson 1976). If poles that offer a good vantage point located in areas of relatively high prey abundance also present a high electrocution risk, they can create a mortality “sink” resulting in ongoing electrocutions (Dickinson 1957, Edwards 1969, Olendorff 1972).

Pole selection by raptors appears to be affected by the degree of surrounding habitat diversity. Notwithstanding vantage point and other factors, raptors tend to select poles (“preferred poles”) in areas of relatively high habitat diversity because a diverse habitat matrix supports greater species richness and, in some cases, locally abundant prey populations (APLIC 1996). If these poles support design characteristics with energized phases and ground structures close enough to result in flesh-to-flesh contact, they can be particularly hazardous and result in numerous electrocutions (Dickinson 1957, Olendorff 1972, Nelson and Nelson 1977).

Nelson and Nelson (1976) filmed extensive behavioral observations of golden eagles approaching and landing on un-energized distribution lines. The purpose of the study was to identify behaviors that exposed eagles to increased electrocution risks during takeoff and landing. Analysis of the observation data revealed that eagles seldom used pole tops or conductors selecting instead cross arm structures that presumably provided better footing. Electrocution risk also increases for raptors carrying prey to roost or nest sites as potentially conductive length increases (Benson 1980, Gillard 1977).

Besides increasing electrocution risk by increasing the conductivity of feathers, rain also elicits a wing-spreading behavior used by raptors to increase circulation around feathers and enhance drying. This behavior also increases the risk of electrocution by exposing out-stretched wings to conductors while the bird is perched (Olendorff 1981). After a protracted storm period, raptors may use poles more frequently than they do during fair weather because perch hunting may be limited during the storm and raptors may be taking advantage of weather breaks by concentrating at pole lines to hunt. This behavior, along with wet poles and lines, could exacerbate an electrocution problem (Hamerstrom, Jr. et al 1974).

Although behavior is not a variable in reducing electrocution risk, it is important that researchers understand how raptors use power lines so that they may design risk-free distribution systems and appropriately remediating hazardous designs.

Pole and Tower Use and Nesting. The use of transmission towers and distribution poles for nesting can present both benefits and hazards to raptors. Currently, pole and transmission tower nesting has been documented in 35 species (mostly raptors) worldwide (Table 3). The overall suitability of towers as a nesting substrate is the subject of some debate. Towers offer several advantages as nest platforms including stability, shading from cross members, and increased cooling from open-air circulation (Van Daele 1980). In addition, transmission towers may support higher raptor populations in areas where nest substrate is a limiting factor (Nelson and Nelson 1976). These meta-populations may serve as source populations for vulnerable or declining species with unstable populations within the species range.

Table 3. Avian Species Documented Nesting on Electrical Transmission Towers and Distribution Poles

Species	***Location***	***Description***	***Source***
9 species	So. San Diego County	Sunderset nuclear power plant	Baldridge, F.A. 1977
Hadeda Ibis *Bostrychia hagedash*	Africa	Transmission line	Brown and Lawson 1988
Egyptian Goose *Alopochen aegyptiacus*	Africa	Transmission line	Brown and Lawson 1988
Osprey *Pandion haliaetus*	California, Idaho, Minnesota, Washington; Mexico	Transmission line	Castellanos et al. 1999, Olendorff et al. 1986, Williams and Colson 1986, Detrich 1978, Henney et al. 1978, Melquist and Johnson 1975, Dunstan 1968
African White-backed Vulture *Gyps africanus*	California; Manitoba, Canada	25-kV and 66-kV distribution lines	Real and Mañosa 1997
Cape Griffons *Gyps coprotheres*	South Africa	Transmission towers	Ledger and Hobbs 1999
Black-Breasted Snake Eagle *Circaetus pectoralis*	Africa	Transmission line	Brown and Lawson 1988
Brown Snake-Eagle *Circaetus cinereus*	Africa	Transmission line	Brown and Lawson 1988
Pale-Chanting Goshawk *Melierax canorus*	Africa	Transmission line	Brown and Lawson 1988
Harris's Hawk *Parabuteo unicinctus*	Arizona	Distribution lines and transformers	Blue 1996
Swainson's Hawk *Buteo swainsoni*	Unknown	Transmission line	Blue 1996
Zone-tailed Hawk *Buteo albonotatus*	Unknown	Transmission line	Blue 1996
Red-tailed Hawk *Buteo jamaicensis*	California; South Africa	Transmission towers	Ledger and Hobbs 1999, Fitzner 1980, Stoner 1939
Ferruginuos Hawk *Buteo regalis*	Idaho, Washington; South Africa	Transmission towers	Ledger and Hobbs 1999, Blue 1996, Gilmer and Wiehe 1977
Black Eagle *Aquila verreauxii*	Africa	275-kV transmission line	Ledger et al. 1987
Tawny Eagle *Aquila rapax*	Washington	Hanford nuclear power plant and assoc. power lines	Fitzner 1980
African Hawk-eagle *Hieraaetus spilogaster*	Idaho	Bird of Prey National Conservation Area	Howard 1980
Martial Eagle *Polemaetus bellicosus*	North Dakota	Commonwealth and United Power Associates	Bridges 1980

Table 3. Avian Species Documented Nesting on Electrical Transmission Towers and Distribution Poles

Species	***Location***	***Description***	***Source***
Red-tailed Hawk *Buteo jamaicensis*	California	Transmission towers	Knight and Kawashima 1993
Prairie Falcon *Falco mexicanus*	Oregon, Unknown	Transmission towers	Blue 1996, Roppe et al. 1989
Greater Kestrel *Falco rupicoloides*	South Africa	Transmission towers	Ledger and Hobbs 1999
Common Kestrel *Falco tinnunculus*	South Africa	Transmission towers	Ledger and Hobbs 1999
Lanner Falcon *Falco biarmarcus*	South Africa	Transmission towers	Ledger and Hobbs 1999
Eastern Screech Owl *Otus asio*	Unknown	Unknown	Blue 1996
Great Horned Owl *Bubo virginianus*	South Africa	Transmission towers	Ledger and Hobbs 1999
Acorn Woodpecker *Melanerpes formicivorous*	California	Distribution pole	Personal Observation, Kevin Hunting
Raven *Corvis corvus*	California, South Africa, Spain	Transmission towers	Ledger and Hobbs 1999, Navazo and Lazo 1999, Knight and Kawashima 1993.
Black Crow *Corvus capensis*	South Africa	Transmission line	Brown and Lawson 1988
Pied Crow *Corvus albus*	South Africa	Transmission line	Brown and Lawson 1988

Fitzner (1980) found that among a variety of substrates from which to select (e.g., buildings, trees, cliffs), 14 percent of great horned owl nests documented in the Hanford, Washington, study area in 1978 were located on transmission towers. Red-tailed hawks and ravens (*Corvus corvus*) selected towers more frequently (52 percent and 37 percent respectively) than any other nesting substrate. Similarly, 9 percent (6 of 57) of nesting ospreys in the Long Valley, Idaho, area selected transmission towers as nest sites and 4 percent of the large osprey population in Idaho used transmission towers during the 1972–1973 season (Van Daele 1980).

Nelson (1982) suggested that transmission towers, which pose no electrocution threat to eagles, were excellent candidates for artificial nest platforms. He cited the abandonment of 20 golden eagle eyries in Idaho and the subsequent Pacific Power and Light Company installation of 12 platforms along transmission lines in the vicinity of the abandoned nests. Four platforms were occupied by raptors (two by golden eagles) during the first nesting season following construction.

Two authors have examined the productivity of raptors nesting on towers, compared to non-tower nesters in the same population and vicinity. Melquist and Johnson (1974) noted slightly lower reproductive success in tower nesting ospreys when compared to ospreys using natural nest structures. Conversely, Gilmer and Wiehe (1977) found that although productivity was higher among tower-nesting ferruginous hawks in Idaho and Washington, overall reproductive success was reduced because overcrowding by fledglings in the nest and loss of nestlings to wind storms reduced fledgling success.

Additional research is required to determine the relative benefits and deficits of tower nesting by raptors.

When evaluating whether the installation of an artificial nesting platform is justified in a particular area, Daele (1980) suggested that land managers should consider: 1) the relative availability of other suitable nesting substrates, 2) research needs of installed platforms, 3) the platform's function as a traditional nest site deterrent or substitute for a problem nest site, and 4) the public relations role of platform.

Tower nesting can be beneficial under a wide variety of environmental conditions. However, additional research is needed to determine the exposure of raptors to electrocution risk in areas where tower nesting is promoted and to learn how environmental factors associated with tower nesting (e.g., shade, predation) affect local productivity.

Age. Juvenile and subadult raptors are more susceptible to electrocution than adults, because they lack flight experience and employ "different" hunting methods than adults (Benson 1980). A review of raptor electrocution data from the late 1970s that represented 24 five-mile stretches of power lines in Idaho, Oregon, Nevada, Utah, New Mexico, and Wyoming reported that 82.5 percent (343) of all electrocution fatalities were golden eagles (EPRI 1982). Age was determined for 52 of the recovered eagle carcasses, and 94.2 percent (49) were juveniles or subadults even though the frequency of use by adult eagles was 38 percent. Boeker and Nickerson (1975) also found that 90 percent (n=419) of golden eagles electrocuted in the western United were juveniles or subadults. In both studies, the frequency of immature and subadult electrocutions was substantially higher than would be expected by the typical proportion of immature and subadult birds in a golden eagle population. Mortality ranged from 29.7 percent (*n*=6383, Wrakestraw 1973) to 39.4 percent (*n*=450, Edwards 1969). A 1976 National Audubon Society study in the United States also found that a high percentage (98%, n=300) of eagle electrocutions were young birds (Nelson and Nelson 1977). In another study of age-specific mortality in golden eagles, Beecham and Kochert (1975) determined the cause of fatality for eagles recovered in the Snake River Canyon, Idaho, and found 12 of 28 (43 percent) were immature birds. Similarly, Harness and Wilson (2001) speculated that juvenile raptors were electrocuted more frequently than adults, based on the time of year in which most electrocution fatalities were reported.

During filming studies to determine behavioral factors that could lead to eagle electrocutions in Idaho, Nelson and Nelson (1976) noted that young birds used distribution lines near their nest site to practice takeoff and landings. These birds lacked the skills to negotiate landings while avoiding wires and were often electrocuted. They noted that typically, adult birds would approach a pole at higher speeds from below a pole and use a combination of gravity and tail and wing breaking to slow flight and alight on a cross arm while juvenile and subadult birds would approach from above and often use vigorous wing-flapping to break prior to landing thereby increasing the time open wings could contact phases and increase electrocution risk.

Age-specific electrocution risk appears to extend to other raptors as well (Fitzner 1978; Gillard 1977). Dawson (1995) noted 37 percent (*n*=112) of electrocuted Harris' hawks (*Parabuteo unicinctus*) in urban environments in Arizona were immature birds. Benson (1980) documented 30 percent of juvenile red-tailed hawk fatality by electrocution occurred in spring months.

Other factors being equal, electrocution risk is clearly higher in young raptors. The literature unequivocally demonstrates inexperience and lack of coordinated landing and flight skills contribute to electrocution risk. The abundance of evidence supporting this conclusion suggests proximity to nest sites and juvenile habitat selection should be considered during distribution system siting.

Electrostatic and EMF Effects. Most potential EMF affects are reported in the literature as observation-based anecdotes and are generally not supported by conclusive studies or empirical evidence. However, several authors have noted the tendencies of some birds to avoid energized wires. Curtis (1997) noted several species avoid landing on wires during peak use hours when lines were under heaviest load and emitted the loudest sound and presumably generated the most vibration. He noted that mourning doves (*Zenaida macroura*) were the only species that seemed unaffected by this phenomenon.

Dickson (1957) observed a bluebird (presumably *Sialia sialis*) attempt to alight on a transmission line eight separate times, eventually flying off to another perch. The author surmised the bird was responding to the electrostatic effects of the line. He cited a personal communication from Dr. Peter Kellogg, Cornell Laboratory of Ornithology, in which several observations led Cornell researchers to conclude that birds seldom land on wires energized at 33-kV or greater. They attributed this phenomenon to feathers being pulled away from the bird's body as a result of static electricity which created an uncomfortable feeling for the bird causing it to abandon perching on the wire.

Most potential EMF affects are reported in the literature as observation-based anecdotes and are generally not supported by conclusive studies or empirical evidence. Probably the worst-case EMF exposure scenario would be a nest located directly beneath the center phase of a single-circuit, 500-kV line in which electrical field levels were measured at 40-kV/m (Lee 1980). Golden eagles (Lee 1980), red-tailed hawks and ravens (Ellis et al. 1978), and martial eagles (Dean 1975) have been observed nesting in this position on transmission towers. However, the effects of prolonged exposure occurring during nesting are unknown (Lee 1980).

EMF effects on wildlife have not been well documented in the literature and may be a topic worthy of future research. However, research directly addressing electrocution mortality is currently a higher priority.

3.3 Electrocution Mortality Assessment

3.3.1 Direct Observations and Dead Bird Counts

Electrocution fatalities are probably initially detected by utility maintenance and repair personnel, and assessment of mortality is most often inferred from carcass counts below power lines (Janns and Ferrer 1999; APLIC 1996; Ferrer et al 1991; Benson 1980; Boeker and Nickerson 1975; Olendorff 1972). Surveys for raptor fatalities or to identify problem poles along power distribution lines is usually time consuming and perceived as cost-prohibitive.

Most studies evaluating mortality utilize ground searches around poles along a prescribed survey transect. Actual counted carcasses become, in effect, a mortality estimate (Curtis 1997; Dawson 1995; Ferrer et al 1991; Janns and Ferrer 1999; Harness 1999b; Hobbs and Ledger 1986; Ledger and Hobbs 1999; Melcher and Sauza 1999; Thelander 1999). Factors biasing mortality estimates, and methods for considering bias factors in mortality estimates, are often neglected in field studies. Some researchers note that raptors are infrequently scavenged and therefore, it is unnecessary to account for scavenging as a bias factor; however, Ferrer et al (1991) noted relatively high (>70 percent) scavenger removal rates during trials under a variety of environmental conditions in Africa. This substantial bias factor suggests fatality counts, at least in Africa, may significantly underestimate actual mortality. Mortality rates are typically not important in identifying problem lines or poles; however background estimates applied to large geographic areas for the purpose of establishing population-level effects may significantly underestimate electrocution mortality.

Assuming scavenger removal of electrocuted raptors is, in part, a function of absolute body size, electrocution of small diurnal (e.g. American kestrel, merlin [*Falco columbarius*]) and nocturnal (e.g., screech owl [*Otus sp.*]) raptors is probably underestimated (APLIC 1996). However, infrequent reports of small raptor electrocution may also be attributed to their relatively short wingspans limiting electrocution risk to terminal poles or poles with transformers.

Several authors have suggested more rigorous and consistent testing is required to standardize direct counting and electrocution mortality estimation methods (Janns and Ferrer (1999); Hobbs and Ledger 1986; Olendorff 1981). In addition, research into the importance of measuring scavenger removal would greatly improve estimation accuracy.

3.4 Mitigation Measures and Suggested Practices

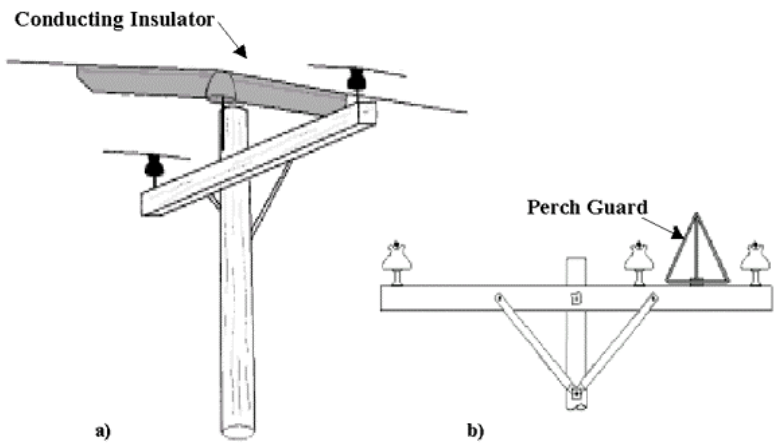

Figure 3: Distribution pole with common mitigation measures - a) Insulator; b) Perch Guard

Reducing and eliminating electrocution risk involves mitigating impacts of existing designs (Table 4; Figure 3) and modifying the design of new structures. Mitigation often consists of the remediation of hazardous structures identified during maintenance activities or brought to a utility's attention. Remediation or design modification is usually pole type-specific; however, poles with like designs are often retrofitted using similar yet untested treatments. Emerging research has demonstrated that monitoring is essential when determining a measure's efficacy under a variety of environmental and physical conditions.

Table 4. Summary of pole modification Measures to reduce electrocution

Measure	*Locations*	*Comments*	*Source*
	Pole Modification Measures		
Phase separation and wire spacing.	Bald eagle range (109 cm (43 inch) phase separation; Montana (43 inch phase spacing), Idaho (5.2 meter phase separation), Idaho (43 inch spacing), Use pole top extension	General measures for distribution line construction	O'Neil 1988, Meyer 1980, Steenhof and Brown 1978, Smith and Nelson 1976, Anderson 1975
Pole perch extensions.	California; Manitoba, Canada; South Africa; Worldwide	General measures for distribution line construction	Mañosa 1997, APLIC 1996, Real and Ledger et al. 1987, Olendorff et al. 1981, Steenhof and Brown 1978, PGE 1946
Add pole-top extension to increase distance between phases.	North America	General guidance for raptor protection	Harness 2001a, APLIC 1996
Lower "neutral" wire on single- phase construction poles.	Worldwide	General guidance for raptor protection	Olendorff et al. 1981
Lower cross arm.	Worldwide	General measure for raptor protection	APLIC 1996, Olendorff et al. 1981

Table 4. Summary of pole modification Measures to reduce electrocution

Measure	*Locations*	*Comments*	*Source*
Replace metal cross arm with fiberglass or wooden arm.	Mexico	Intended for concrete three-phase tangent and double dead-end poles	Harness 2001a
Insulate/cover conductors or jumpers.	Bald eagle range, Arizona: South Africa, Spain	General measures for distribution line construction	Janns and Ferrer 1999, Ferrer et al. 1991, Nobel 1995, Ledger et al. 1987, Steenhof and Brown 1978
Insulate jumpers and transformers on corner poles.	Idaho, Nevada, New Mexico, Oregon, Utah, Wyoming; Worldwide	General guidance for golden eagle and raptor protection	APLIC 1996, EPRI 1982, Olendorff et al. 1981
Insulate middle phase over pole top.	Worldwide	General guidance for raptor protection	APLIC 1996, Olendorff et al. 1981
Install non-conducting link extensions to center phase on corner poles.	Worldwide	General guidance for raptor protection	APLIC 1996, Olendorff et al. 1981
Cover outside conductors on single-phase, three-arm poles.	North America	General guidance for raptor protection	APLIC 1996
Use of non-conductive bracing material.	Bald eagle range; Worldwide	General guidance for raptor protection	Olendorff et al. 1981, Steenhof and Brown 1978
Extend insulators to increase distance between phases.	North America	Intended for 69-kV horizontal post designs	Harness 2001a, Janns and Ferrer 1999, APLIC 1996
Ground wire gaping.	Worldwide	General guidance for raptor protection	APLIC 1996, Olendorff et al. 1981
Terminate ground wire at least 24” below energized phase.	North America	Intended for single phase, side-mount pole design	APLIC 1996
Suspend jumpers and/or conductors.	Spain	General measures for distribution line construction	Janns and Ferrer 1999, APLIC 1996, Ferrer et al. 1991
Install triangular “eagle guards” between phase insulators.	Idaho, Nevada, New Mexico, Oregon, Utah, Wyoming; Worldwide	Used in conjunction with other measures	Harness 1999b, APLIC 1996, Olenorff et al. 1981
Install other perch guard designs between phases and over insulators.	Spain	General raptor protection measure	Janns and Ferrer 1999
Install (SVD [~BVD]) on line centered over suspended insulator.	North America	Use on “wishbone” design poles	APLIC 1996
Locate transformers away from poles.	South Africa	General raptor protection measure	Ledger et al. 1987
Install artificial nest platforms.	Idaho, Montana, Oregon	Prescribed in response to high activity areas	Meyer 1979, Nelson 1979
Relocate transmission tower nests.	Idaho	Based on EPA guidelines	Lee 1980
King bird effigies to reduce corvid use thereby reducing secondary raptor use.	North Dakota	Attempted in a single study. Results not reported.	*In:* Dickinson 1957

Table 4. Summary of pole modification Measures to reduce electrocution

Measure	*Locations*	*Comments*	*Source*
	Monitoring		
Monitor mortality and correct problem poles.	Bald eagle range	Only study recommending monitoring	Steenhof and Brown 1978
Continuing carcass surveys to identify and correct problem areas.	Idaho, Nevada, New Mexico, Oregon, Utah, Wyoming	General guidance for golden eagle protection	EPRI 1982
Monitor in homogenous habitat after reported electrocution.	North America	Monitoring to determine culprit pole(s)	APLIC 1996
Monitor mortality at poles where electrocution has been reported.	North America	Monitoring to distinguish isolated events form recurring problems	APLIC 1996

The following summarized chronology of mitigation measure development is intended to establish a basis for identifying future mitigation measure research needs and describing source information for current measures.

In 1975, the Raptor Research Foundation, Inc., (Miller et al 1975) prepared for the Edison Electric Institute the first comprehensive collection of suggested practices for eliminating raptor electrocution. The document contained 10 recommendations dealing with pole structure, phase separation, perches, transformer and jumper line insulation, and gaping, or not grounding, pole ground wires. This document was the precursor to the more comprehensive *Suggested Practices* document prepared by Olendorff et al (1981).

Steenhof (1978) recounted a few of the recommendations cited in Miller et al (1975) and added a monitoring requirement for distribution lines constructed near bald eagle wintering areas in Idaho. This is the first mention and requirement for monitoring in the literature.

The publication of *Suggested Practices for Raptor Protection on Power Lines: The State of the Art 1996* (APLIC 1996) updated Olendorff et al (1981) and provided additional insights into the electrocution problem. This document acknowledged that golden eagles were the species most at risk from electrocution and identified specific distribution pole types as most hazardous. APLIC (1996) suggests the following general guidelines for mitigating electrocution and identification and remediating existing hazardous distribution lines:

1. Older poles are usually most hazardous, particularly those with metal or short crossarms and close proximity between energized phases and grounding structures.

2. Electrocution is a distribution line problem with low electrocution hazard on lines less than 69 kV. (Note: transmission and distribution line definitions differ between

countries. Generally, systems carrying greater than 68kV are not hazardous because of adequate spacing of energized parts.)

3. Poles preferred by raptors and those demonstrated as particularly lethal should be top remediation priorities.

4. Pole lines in homogenous habitat areas (presumably with equal probability of raptor usage) should be monitored to determine degree of hazard.

5. Reported electrocutions should be closely evaluated to distinguish isolated events from recurring problems. Monitoring of reported electrocution poles should consider: a) prey availability, b) terrain and visibility advantage, and c) consistent use for still hunting.

6. Poles supporting hardware such as transformers, jumper wires, switches, etc., are more likely to cause electrocution.

7. The most costly component of pole remediation is labor and travel.

APLIC (1996) also describes specific measures for modifying existing pole designs to reduce or eliminate avian electrocution risk. Some of these measures are adopted from previous works, but many are unique to the *Suggested Practices* document. Although many of these measures have been employed under field conditions, the literature lacks documentation of the effectiveness of most measures.

In an early note of protective devices for golden eagles, Marshall (1940) found that service interruptions along a 100-mile stretch of 20 kV distribution line near Boise, Idaho, were eliminated with the installation of eagle guards (perch prevention devices). However, as noted below, pole design and proper guard application are essential to reduce electrocution risk.

Case studies of implementation of some of these practices points to the need for tailoring detection, monitoring, and remediation activities to individual poles or pole reaches. Janns and Ferrer (1999) estimated that approximately 90 percent of all power poles in Western Europe were steel and outdated or damaged wooden poles were being replaced with steel poles. They evaluated accepted remediation and mitigation measures for reducing electrocution risk on wooden poles and found that many of these methods were not effective or, in some cases, *increased* electrocution risk. For example, a commercially available perch guard recommended by a French utility actually increased electrocution incidence and risk by forcing birds closer to energized phases. Harness (1999c) noted that remediation measures described in APLIC (1996) were probably not applicable to concrete pole designs in Mexico. Harness (2001b) also noted that installation of eagle guards were not always effective and in the case of Moon Lake Electric Association's power lines in

Colorado and Utah, these guard structures actually resulted in increased electrocution hazard by forcing birds closer to energized phases. In addition, bushing covers with small drain holes (intended to insulate power line bushings) created electrocution problems as passerines often probed for insects through the small drain hole and were electrocuted. Similarly, as part of a survey of retrofitting effectiveness, PGE found that 65 percent of retrofits were improperly installed and an additional 15 percent had degraded (Dedon 1999).

Janns and Ferrer (1999) recommend evaluating installation of remedial devices for at least one year (all seasons) on individual poles and affected pole lines to determine device efficacy. Furthermore, Negro and Ferrer (1995) noted that individual pole design and environmental conditions should be evaluated before implementing remediation, and assessment of effectiveness requires post-installation monitoring. In addition, Bayle (1999) noted the importance of conducting behavioral observation studies prior to initiating potentially costly retrofit mitigations citing the above failed attempts and those aimed at preventing electrocutions of griffon vultures (*Gyps fulvus*) in France. In these cases, power line managers and administrators made assumptions regarding causes of fatality based on experiences in other regions or professional opinions.

An important component of effective mitigation measure implementation is cost. Measures that are the most effective at reducing or eliminating risk at a relatively low cost will have the best chance of implementation. While APLIC (1996) acknowledges cost as a factor in determining appropriate measures, the literature contains very little mitigation cost information. Laycock (1973) estimated that “preventable” electrocution problems at power poles could be remediated at a cost of $135 (1973 dollars) per pole. The system developed by Kruger (2001a), using a risk-based approach to implementing electrocution mitigation measures in South Africa, offers a quantitative and systematic method for identifying and implementing measures and is a sound model for use in the U.S. and California.

Rules for constructing distribution lines are set forth by General Order No. 95 (CPUC 1981). Incorporating bird-safe designs into the building requirements would greatly reduce the incidence of bird electrocutions. For instance, simply placing hardware components under crossarms rather than above crossarms would nearly eliminate the potential for bird contact with these components. Other requirements that would reduce risk include greater phase separation between components, eliminating metal crossarms, and using insulated components such as fuse cutouts, lightening arresters, and cable terminators. Such requirements would result in greater production of bird safe designs, and therefore, reduced costs. Additionally, training linemen to understand and install bird safe designs would result in fewer electrocutions.

Identification of problem poles, on both a local and regional basis, is important in determining priorities for remediation and design modifications. Problem poles are often discovered opportunistically, which makes it difficult to determine whether they represent an isolated case or part of a much larger regional problem. Systematic searches and reporting are needed to set mitigation and remediation priorities. Requiring bird safe pole designs be incorporating these into legal building requirements would greatly reduce electrocution risk.

3.5 Biological Significance

The statewide, national, and global impact of electrocution from power distribution structures on raptor populations is difficult to assess. However, it is probably safe to assume that although electrocution impacts are ongoing, population-level impacts to species with smaller body size and shorter wingspans are negligible. Several examples of local and regional population effects have been documented and serve to illustrate the severity of electrocution as a population decline factor under especially hazardous conditions.

In a study conducted in Doñana National Park in southwestern Spain, Ferrer et al (1991) concluded that electrocution was resulting in a “serious” population-level impact. Sixty-nine percent of all Spanish imperial eagle (a Spanish endangered species) fatalities during the five-year period from 1986 to 1991 were attributed to electrocution. In a companion study of sex-biased mortality covering roughly the same time period, Ferrer and Hiraldo (1991) found that 78 percent of electrocuted imperial eagles in Spain were females which seriously reduced the capability of this endangered raptor—with its naturally low reproductive rate and small populations—to recover.

Evaluating several European studies of raptor fatalities associated with power lines, Bayle (1999) found that 93 percent of all mortalities were from electrocution and the remaining 6.5 percent were from power line collisions. This study focused on evaluating bird interactions with power line and electrical distribution systems and illustrates the effects of very hazardous pole designs. Similarly, a study of population demographics and conservation of Bonelli’s eagles (*Hieraetus fasciatus*) in Spain and France, Real and Mañosa (1997) documented electrocution as the primary cause of decline in this species in the region. They noted low adult survivorship as the main contributing factor to declining productivity.

Companion studies of dead eagles submitted to the National Wildlife Health Laboratory between 1963 and 1984 (National Wildlife Health Laboratory 1985) and between the mid-1960s and early 1990s (Franson et al 1995) suggest a range of bald and golden eagle mortality rate values that could be applied on a nationwide scale to estimate population-level effects. The National Wildlife Health Laboratory (1985) reported a mortality rate of 9.1 percent (130 of 1429) for bald eagles attributable to electrocution while Franson et al (1995) reported mortality rates of 25 percent for golden and 12 percent for bald eagles. In a study of bald eagle movements and survival, Harmata et al. (1999) reviewed the cause of death of 57 recovered eagles banded both inside and out of the Greater Yellowstone ecosystem between 1979 and 1998. Cause of death was determined for 42 of 57 birds recovered, with electrocution reported in 20 percent (10 of 42) of recoveries. Electrocution was the leading cause of fatalities in this study.

Nelson and Nelson (1977) called the loss of golden eagles to electrocution in the United States "significant" and noted that the problem is probably more severe in states with lower golden eagle populations. This observation is supported by national studies in which mortality rates can be estimated for bald and golden eagles. For example, Phillips (1985), in a study of eagle fatalities throughout the western United States, found that 300 of 375 (80 percent) of golden eagle fatalities were caused by electrocution. Hunt (2002) attributed electrocution in 12 percent of 100 golden eagle fatalities in west-central California. Similarly, the World Working Group on Birds of Prey and Owls (1991) concluded that electrocution was the second greatest threat to birds of prey in Czechoslovakia behind nest robbing.

In contrast to the conclusions of most researchers, Snow (1973), in an account of the northern and southern bald eagle in the Bureau of Land Management (BLM) Habitat Management Series for Endangered Species, assumed electrocution is a "minor" impact relative to shooting and that insufficient data exist to determine population-level impacts. However, the author noted that local impacts may be considerable.

The results of these observations and studies suggest that hazardous pole and equipment designs (e.g., those described in APLIC 1996) combined with other physical and biological factors, can lead to high-risk conditions in which raptor electrocution mortality can be severe enough to effect local raptor populations. Studies of the effects of hazardous designs on golden eagles (Nelson and Nelson 1976; Franson et al 1995; Boeker and Nickerson 1975; Olendorff 1972) suggest a regional population effect that could extend throughout the intermountain west and western plains states.

Despite perceptions by some that the avian electrocution problem was solved in the 1980s and 1990s, there is evidence to suggest that electrocution is, at a minimum, a persistent problem and may be growing (Lehman 2001). The addition of hundreds of thousands of kilometers of distribution lines in the past decade-coupled with increased awareness of the problem's potential by industry and the regulatory community-have led to renewed skepticism and concern over the magnitude of electrocutions.

3.6 The California Perspective

Although California is among the states that possess the highest biodiversity in North America, it is lacking in both assessment and management of avian electrocution fatalities. Accounts of avian electrocution in the published literature are rare (seven of 158 published accounts documenting electrocution in California in the literature cited for this report) and, due to the lack of reporting requirements in the state, anecdotal reports are infrequent and often non-specific.

A report from southern California documented raptor electrocution in the San Diego area (Balridge 1977); the California Bald Eagle Working Team (1985) documented electrocution accounts of bald eagles in northern California; Woodbridge and Garrett (1993) attributed bald and golden eagle electrocution to areas of high prey concentrations coupled with hazardous conditions; and Hunt (2002) reported electrocution was responsible for 12 percent of golden eagle deaths near Livermore, CA. The other California reports either recommended avoidance and mitigation measures (Olendorff et al 1986) or described hazardous conditions or tower nesting (Detrich 1978; Henny et al 1978; Williams and Colson 1988).

Currently, there are no requirements for reporting or documenting electrocution fatalities in California (Linda Spiegel, pers. comm.). Lehman (2001) points out that information collection, management, and sharing are lacking even among the most proactive companies. This lack of information is attributable, in part to the absence of requirements to do so in a deregulated, and more competitive, energy environment, and by industry concerns that these data could be used to initiate costly and potentially damaging enforcement actions (Lehman 2001). Industry and the regulatory community need a systematic and reliable reporting process to evaluate fatality on a regional or statewide basis. Assessment of on-going electrocution as a population-level effect will be difficult, if not impossible, unless a more comprehensive and inclusive approach to reporting is established.

Despite the lack of reported electrocutions, the potential for a widespread and significant electrocution problem in California is very real. California is host to 618 bird species, (California Bird Records Committee 2001) of which 23 are diurnal and 14 are nocturnal raptors. Of these, 15 diurnal and 6 nocturnal species have wingspans or body sizes sufficient to present an electrocution risk. California's coast and Central Valley are known migratory paths for fall and spring raptor movements (Golden Gate Raptor Observatory, Unpubl. Data) often concentrating birds in urban areas that support dense electrical distribution systems.

Compounding the electrocution risk potential is the growing human population in California. Although there are no estimates of the linear extent of distribution lines in California, (approximately 200,000 miles and 4.2 million poles) their close relationship to human population size and distribution suggests extensive California networks. Since the degree to which incorporation of design features that reduce electrocution risk is unknown, it is possible (even likely) that most distribution systems pose at least a moderate risk to raptors. The risk is magnified by weather (e.g., persistent winter valley fog and summer coastal fog), physiognomic factors (e.g., spatially and temporally diverse and dynamic landscape), and the preponderance of relatively high-risk distribution poles and structures.

A sustained and focused research effort is required in California to determine the extent and magnitude of avian, especially raptor, electrocutions. Chronic population-level effects, at least within a seasonal timeframe, are possible as are the potential for population "sinks" in areas where risk factors combine to exacerbate an existing problem. Combined with a rigorous reporting and information exchange network, a California research plan should focus on systematic problem area identification and remediation.

3.7 The Legal Context

In the United States, most birds are protected under the Migratory Bird Treaty Act (MBTA; 16 U.S.C. 703–712) that 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 $250,000 for misdemeanor and $500,000 for felony violations.

In California, birds may be further protected by a number of laws: 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 literature provides few examples of successful litigation under the state and federal laws described above on behalf of birds and still fewer in relation to electrocution. Cases of chronic population-level electrocution impacts on seriously declining species often attract public and civic scrutiny that may be a more effective motivating factor for remediation than the threat of litigation. For example, Eskom—South Africa's largest electric utility—agreed to construct (or regulate construction of) only "bird friendly" transmission and distribution lines as a result of considerable public attention on raptor electrocution and the identification of electrocution as a primary decline factor for threatened raptor species (Ledger and Hobbs 1990).

Few cases involving bird electrocution are actually tried in court as most litigants prefer to mitigate and/or retrofit power lines to completely avoid electrocution impacts. One notable case of prosecution under the Migratory Bird Treaty Act and Eagle Protection Act for electrocution is the 1999 sentencing of the Moon Lake Electric Association to three years probation and a fine of $10,000 for electrocution of 17 eagles and hawks near Rangely, Colorado (Harness 1999a).

In a 1999 address to the Edison Electric Institute (EEI), U.S. Fish and Wildlife Service (USFWS) Director Jamie Clark extended the Service's cooperation to industry stating a willingness to work closely with companies approaching the problem in a proactive way.

Although voluntary compliance was the overt message, a gentle reminder of the recent Moon Lake case, and the USFWS enforcement powers with respect to the MBTA, may be an indication of a renewed willingness by the USFWS to enforce migratory bird and raptor protection laws.

3.8 Issues Summary

Avian electrocution is an ongoing problem first documented in the United States in 1922. The problem occurs primarily on distribution line systems but has been reported on transmission lines outside of North America. The root of the problem is the distance between energized phases, conductors, transformers, and other conducting structures to one another and grounded structures is less than the skin-to-skin contact length of some bird species. The continuing problem stems from lack of remediation of hazardous poles and related structures and continued construction of hazardous poles and structures.

Golden eagles appear to be more susceptible to electrocution than most species due to a combination of biological, physiognomic, and pole design factors. For some species, including the golden eagle, electrocution mortality can be a population-level factor, or primary factor contributing to population declines. Electrocution mortality for most species is a localized, but potentially significant, problem resulting from particularly hazardous pole design in areas conducive to high raptor use. Given the vast network of distribution lines in the state today, as well as the need for more lines in the future, the number of birds being electrocuted is likely in several hundreds of thousands annually.

Despite significant early strides to identify hazardous pole and distribution system structure designs, there is a growing body of evidence that some of the measures and recommendations in the *Suggested Practices* document (APLIC 1996) require more thorough testing before deemed effective. Remediation measures and design features considered *a priori* to be effective in reducing electrocution fatalities have been proven less effective than originally thought and, in some cases, remediation measures have actually increased electrocution risk.

Requirements for reporting raptor electrocution are lacking in western states making identification of the scope and magnitude of the problem impossible. A comprehensive monitoring strategy that includes a reporting requirement is needed to begin gathering information that would allow impact quantification.

3.9 The PIER Focus

As noted throughout this roadmap, there is a lack of data on avian electrocution as a result of interactions with power lines in California. The lack of readily accessible data has also led to a poor understanding of the effectiveness of mitigation technologies and strategies for specific bird populations and environments. Better communication, publication of results in scientific journals and peer reviewed publications, and a clearinghouse for data and information exchange would promote increased identification of problem areas and improve efforts aimed at finding effective solutions.

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 electrocutions as a result of interactions with power lines is one such issue. 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 collisions 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 factors influencing electrocution risk and described actions intended to reduce or eliminate this risk. This section focuses on current research and short-, mid-, and long-term research needs for expanding our knowledge of the problem, identifying and refining mitigation measures, and developing new structure- and region-specific measures. The research needs identified in this section are designed to fit a hierarchical and adaptive research model which resolves risk assessment, risk reduction, compliance monitoring, and technology transfer. Mid- and long-term goals are intended to build on research results from short-term programs and provide a foundation for ultimately achieving risk reduction and providing the research tools and information necessary to monitor electrocution impacts. At present, research needs to focus on:

1. Standardize Mortality Estimation

2. Electrocution Risk Assessment

3. Risk Reduction Research and Development

4. Standardized Monitoring Protocol

5. Update Standard References and Building Codes

6. Reporting Requirement and Data Clearinghouse

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.

Edison International (Edison) and Pacific Gas and Electric (PG&E) have avian protection programs and both have been very active and instrumental in APLIC. Edison's program includes reporting protocol, identifying high raptor use areas, retrofitting poles known to cause multiple electrocutions, a GIS based information system designed to alert field lineman of past electrocutions, and developing a predictive risk assessment model. PG&E has recently signed a Memorandum of Understanding with Fish and Wildlife Service committing this utility to specific actions to reduce current levels of avian mortality and to implement avian protection plans. These actions include requirements to retrofit known problem poles. PG&E is also developing a predictive risk assessment model. However, data dissemination and collaboration necessary to determine the statewide extent of avian electrocutions and possible solutions are still lacking. Some of the goals and objectives stated below would provide collaborative opportunities that build upon these efforts.

4.1 Standardize Mortality Estimation Protocol.

Evaluating the biological significance of electrocution mortality has been hampered by a lack of standardized data collection, analysis, and reporting. As described in Section 3, estimates of fatalities typically involve direct counts of birds recovered under poles that exhibit signs of electrocution. The direct count method of estimating electrocution rates (electrocution fatalities per unit time and distance) does not account for factors such as scavenger removal that could greatly influence mortality rates. Past research has demonstrated that raptors and other large birds killed by electrocution are scavenged and the possibility of a "scavenger effect" (scavengers recognizing and capitalizing on areas providing a consistent supply of carcasses) may confound accurate estimation. Agreement on methods would, at a minimum, promote comparison between results of future studies.

Research Needs

1. Develop standardized survey protocols and analysis metrics (consistent with recommendations in Strickland and Anderson [2001]) to determine mortality from electrocutions and investigate the need to incorporate scavenger removal and other bias factors in mortality estimation calculations.

4.2 Electrocution Risk Assessment

There is currently no systematic method of assessing electrocution risk of various pole designs under various environmental (e.g., surrounding habitat types, bird concentration areas) conditions. Janns and Ferrer (1999) developed an experimental design for conducting field and control trials of pole designs, and some hazardous designs and features have been identified (Harness and Wilson 2001). However, systematic field trials to identify and rank the electrocution risk of each design are lacking. Direct field observations coupled with controlled laboratory testing are needed to clearly identify and rank hazardous designs within the context of field conditions that could exacerbate electrocution risk. Moreover, tools to assist in the short- and long-term evaluation and ranking of sites are lacking and should be developed on a site-specific basis.

Research Needs

1. Based on the experimental design developed by Harness (2001c) and Janns and Ferrer (1999), field and control trials of pole designs should be conducted to determine hazardous designs, refine the information in APLIC (1996), and to identify and rank the electrocution risk of each design. Risk evaluation studies should take into account design characteristics known to be of high risk as identified by APLIC (1996), Harness and Wilson (2001), Lehman (2001), and others, the intended deployment area, and the species that are most at-risk in the vicinity of deployment.

4.3 Risk Reduction Research and Development

Early research and development efforts identified several devices and techniques for improving pole designs and retrofitting poles to reduce electrocution risk (see APLIC 1996). In some cases, these initial attempts have reduced risk. However, a growing body of evidence suggests that these designs may not be effective under the wide array of field conditions found in California. In some cases, research has shown that past designs have actually increased electrocution risk. Additional research, development, and testing are needed to improve on past designs and develop new devices and techniques targeting specific locations, conditions, and species. Risk reduction research should also focus on development of a risk assessment and reduction model that could predict electrocution risk based on the range of environmental and physical factors identified in this roadmap. The risk assessment model presented by Kruger (2001b) is an example of integrative assessment incorporating both biological and physical risk factors. Finally, workers responsible for retrofitting lines need to be well trained to ensure proper installation and identify faulty designs.

Research Needs

1. Based on information developed during risk assessment studies and research conducted after publication of APLIC (1996), develop new devices and techniques for mitigating electrocution hazard.
2. Develop risk assessment and reduction predictive model that could be used by industry and regulatory community to help identify potential problem poles and areas.
3. Support APLIC's training workshops on *Suggested Practices for Raptor Protection on Power Lines: the State of the Art in 1996* and incorporate the legal and management commitment elements of the comprehensive program currently being installed by the Colorado Springs Utility (Hurley 2001).

4.4 Standardized Monitoring Protocol

As stated throughout this roadmap, California does not currently require monitoring to detect and evaluate avian electrocution. Growing evidence in the literature suggests some practices in APLIC 1996 may, in some instances, be ineffective or actually increase fatalities (Jaans and Ferrer 1999, Lehman 2001). Indeed, there may be a basis for concluding that electrocution fatalities by distribution lines and structures is a growing problem despite the widespread perception that risk-reduction designs have been effective in decreasing electrocution fatalities (Lehman 2001). Development of a standardized method for monitoring distribution and, if necessary, transmission lines to determine electrocution fatalities would promote comparison between locations and designs and pave the way for more refined mitigation.

Research Needs

1. Develop a standardized pole and structure monitoring protocol for California that incorporates the entire range of physical and biological risk factors.

4.5 Update Standard Avian Electrocution Reference and Building Codes

Two publications have become standard references for researchers who address avian power line electrocution issues: *Avian Collision and Electrocution: An Annotated Bibliography* (CEC 1995) and *Suggested Practices for Raptor Protection on Power Lines: The State of the Art in 1996* (APLIC 1996).

The Energy Commission bibliography (CEC 1995) is currently being updated to include the most current published and unpublished research and revised to include additional cross reference options and improve accessibility. This effort will result in an up-to-date and comprehensive information resource for industry and the regulatory community and should promote standardization of research methods and techniques. In addition to references published since 1995, in-house industry reports that were not available for PIER's roadmaps will be included.

Although widely cited and acknowledged as a comprehensive information source for power line electrocution fatality, the APLIC (1996) document is also in need of an update. Research methods and techniques, mitigation and remediation measures, and emerging technology development have advanced significantly since the document's publication in 1996. To maintain a leadership role with respect to the electrocution fatality problem, APLIC should lead the revision of this document with shared input from industry, agencies, and current researchers.

Distribution line construction rules are provided in the California Public Utilities Commission's (CPUC) General Order No. 95 (CPUC 1981). These rules do not include bird-safe practices and standards yet incorporating such standards would greatly reduce electrocution risk.

Research Needs

1. Industry, the regulatory community, researchers, and the public need a readily available and current information source for avian electrocution issues. Supporting the revision of *Suggested Practices for Raptor Protection on Power Lines: The State of the Art in 1996* would address this goal. This update would incorporate the latest techniques and approaches for mitigating electrocution fatalities.
2. Using information from the revised *Suggested Practices*, support the development of recommended changes to CPUC's General Order No. 95 that would require incorporation of bird safe standards.

4.6 Develop System-Wide Reporting Requirements

A reporting system would require routine and systematic collection of minimum data related to location, type of bird, hardware involved, and environmental conditions. The information should be provided to a centralized database so that all data are available to researchers and other interested parties. The first step in development of a reporting requirement should be a scoping study to document policy needs and identify impediments to a reporting process. Concurrently, development of a centralized data and information clearinghouse would promote use and dissemination of current research and monitoring results.

Research Needs

1. A Data and Information Clearinghouse on avian power line electrocution issues should be established to facilitate research. A clearinghouse approach to data and information storage and stewardship would enhance data availability, make current and emerging techniques broadly available for use and review, and alleviate the need for costly publication revisions. A common data and information clearinghouse established within a regulatory entity would require support for active maintenance and use.
2. Commission a scoping study that involves industry, researchers, and the regulatory community in identification of reporting needs and benefits.

5. Goals

The goals of PIEREA avian electrocution research are to help California benefit from reduced electrocution of birds and to improve system reliability by reducing outages associated with avian electrocutions. Approximately 10 percent of all outages in the state are caused by wildlife and bird-caused outages are the third leading cause of all outages in Pacific Gas and Electric's territory (Dedon 1999). Power outages caused by electrocutions can result in economic losses approaching $1 billion annually. (CEIDS 2001)

The achievement of these goals depends on accurate assessment of avian electrocution risk from power lines and structures, as well as the ability of regulators and utilities to recommend and implement effective technologies and methods for avoiding or mitigating such electrocutions.

The goals developed for the avian electrocution roadmap are based on the information summary and synthesis developed in previous sections, recommendations from members of a Technical Advisory Team that was assembled to address this issue (see Appendix B), and from discussions with California Energy Commission staff.

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

Appendix C summarizes the top priority research objectives described below and identifies potential partnership and cost information, as well as success factors and potential impediments.

5.1 Short-term Objectives[2]

5.1.1 Standardize Mortality Estimation

A. **Develop or identify a standardized method for estimating electrocution mortality incorporating scavenger bias ($50K).**

Activities needed: (1) Convene a team of researchers and representatives from industry and the regulatory community to evaluate the methods used to estimate mortality and appropriate use of scavenger and other bias factors. 2) Develop a framework for standardized data collection, field methods, and expression of electrocution mortality.

Critical Factors for Success:

- Consensus among agency, utility, and regulatory researchers on methods and reporting.

5.1.2 Electrocution Risk Assessment

A. **Determine the relative electrocution risks associated with various pole and distribution structure designs ($200K).**

[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.

Activities needed: (1) Assess electrocution risk potential across all pole designs used in California using appropriate sample sizes.

Critical Factors for Success:

- Cooperation from utilities.

5.1.3 Risk Reduction Research and Development

A. **Begin or expand research and development efforts focusing on modified and new structure and remediation device designs ($1,000K).**

Activities needed: (1) Fully evaluate the strengths and weaknesses of current mitigation and remediation device designs and create new designs with the objective of reducing electrocution risk.

B. **Develop a risk assessment model ($75K).**

Activities needed: (1) Based on the assessment in 5.1.2.A, develop a risk assessment model that researchers, developers, and decision makers can use to assess the risk of different pole and structure types in a particular area. Incorporate design factors and landscape and species-specific biological factors (i.e., relating pole or structure designs to species known to be at high risk for these designs).

C. **Develop and support an updated training course of APLIC's *Suggested Practices* for reducing bird electrocutions ($200K).**

Activities needed: **(1) Based on the revised publication of APLIC's Suggested Practices, develop an updated course to train line workers in state of the art remediation equipment and installation. Courses should be offered throughout the state.**

Critical Factors for Success:

- Ongoing cooperation within the electrical distribution industry and APLIC will be essential to the success of monitoring and training.

5.1.4 Develop Standardized Monitoring Protocol

A. **Develop a standardized method for monitoring pole lines to determine electrocution mortality rates and electrocution events ($45K).**

Activities needed: (1) Convene industry, the regulatory community, and researchers to develop a standardized protocol for consistently monitoring electrocution mortality from pole lines.

Critical Factors for Success:

- Cooperation and participation by industry

5.1.5 Update Avian Electrocution Document and Develop Bird Safe Electrical Line Building Codes.

A. **Update Suggested Practices for Raptor Protection on Power Lines: The State of the Art in 1996 ($50K).**

Activities needed: (1) Research and incorporate studies that have been conducted since the report was published in 1996.

B. **Develop bird safe construction guidelines that could be adopted by CPUC and possibly incorporated into future revisions of General Order No. 95 ($50K).**

Activities needed: Using the information the revised APLIC document, develop raptor safe construction practices and retrofitting techniques that could be incorporated into CPUC's existing General Order No.95, rules for constructing overhead lines.

Critical Factors for Success:

- Cooperation of industry in providing unpublished, in-house reports.
- Coordination with APLIC.
- Guidelines adopted by CPUC.

5.1.6 Develop System-Wide Reporting Requirement.

A. Commission a scoping study to document policy needs and potential impediments to implementing a reporting policy ($45K).

Activities needed: (1) Prepare a scoping document with input from industry, the regulatory community, and researchers that contains a detailed description of policy needs and potential impediments to implementation. The document should describe, in detail, the feasibility and mechanics of affecting policy change.

Critical Factors for Success:

- Initial funding for document preparation.

B. **Research and Create a Clearinghouse for Data and Information Relating to Avian Electrocution ($50K).**

Activities needed: (1) Develop a database structure and storage and maintenance system for centralized management of avian electrocution data. The system should also support a searchable index and ready access to data.

Critical Factors for Success:

- Initial funding for system development.

Table 5. Short-term Budget

Objective	**Projected Cost ($000)**
5.1.1.A Develop or identify a standardized method for estimating electrocution mortality.	50
5.1.2.A Determine the relative electrocution risks associated with various pole and distribution structure designs under a variety of environmental conditions.	200*
5.1.3.A Begin or expand research and development efforts focusing on modified and new structure and remediation device designs	1,000
5.1.3.B Develop a risk assessment model	75
5.1.3.C Develop and support updated APLIC training courses	200
5.1.4.A Develop a standardized method for monitoring pole lines to determine electrocution mortality rates and electrocution events.	45
5.1.5.A Update and revise *Suggested Practices for Raptor Protection on Power Lines: The State of the Art in 1996.*	50*
5.1.5.B Develop bird safe construction guidelines suitable for CPUC adoption	50
5.1.6.A Commission a scoping study to document policy needs and potential impediments to implementing a reporting policy	45*
5.1.6.B Research and Create a Clearinghouse for Data and Information Relating to Avian Electrocution.	50
Total	**$1,765**

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

5.2.2 Electrocution Risk Assessment

A. **Continue Risk Assessment of Pole Designs.**

Activities needed: (1) Continue risk assessment of any new pole designs or those not covered under 5.1.2.

5.2.3 Risk Reduction Research

A. **Expand risk reduction experiments under varied environmental conditions.**

Activities needed: (1) Expand risk reduction tasks described in 5.1.3 to include testing and evaluation under varying field conditions and incorporating the range of physical and biological factors described in this Roadmap.

5.2.4 Monitoring Program Development

A. **Monitoring program expansion**

Activities needed: (1) Expand monitoring protocol developed under 5.1.3 as more information and new remediation devices are designed.

5.2.6 Data and Information Clearinghouse

A. **Facilitate data and information storage and retrieval system**

Activities needed: (1) Provide the support necessary to help facilitate the formation of a data storage and retrieval system determined under 5.1.6.

5.3 Long-term Objectives

5.3.2 Electrocution Risk Assessment

A. **Continue risk assessment on a site- and species- specific basis..**

Activities needed: (1) Adaptively modify assessment of risk potential of various pole designs and structures. Integrate these tasks into a unified program involving industry and the regulatory communities.

5.3.3 Risk Reduction Research

A. **Update and evaluate risk assessment model**

Activities needed: (1) Update and evaluate the risk assessment model developed under 5.1.3

B. **Continue Research and Development of Devices and Techniques**

Activities needed: (1) Continue R&D tasks described in 5.1.3 and 5.2.3. 5.1.3

5.3.5 Update Relevant References

A. Update CEC's annotated bibliography and APLIC's guidelines as necessary.

> *Activities needed*: (1) Using the information available in the data clearinghouse, update relevant references to disseminate data.

5.3.6 System-Wide Reporting Requirement

A. **Review reporting requirement**

> *Activities needed:* (1) Based on the results of the scooping study described in 5.1.6, and assuming policy changes supporting this requirement have been established, review the process for reporting requirement described in 5.1.6 and revise procedures as necessary.

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 support PIEREA efforts.

The questionnaire (see Appendix B) disseminated as part of this roadmap effort was developed, in part, to poll 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 California Energy Commission, the Electrical Energy Institute (EEI), the Avian Power Line Committee (APLIC), and the U.S. Fish and Wildlife Service (USFWS). New funding sources identified during the questionnaire process include the National Renewable Energy Laboratory (NREL) and the National Wildlife Research Center (NWRC).

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., Raptor Research Foundation) 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-sponsorship opportunities are likely with EPRI, EEI, APLIC, the USFWS, NREL, and the NWRC. Each of these organizations is interested in addressing avian electrocution issues. The following specific collaborative opportunities have been identified:

- Cooperate with APLIC to support the revision of *Suggested Practices for Collision Interactions: The State of the Art in 1996.* Edison Electric Institute / Raptor Research Foundation, Washington, D.C
- Nearly all of the goals stated above require cooperation with Edison and PG&E. Therefore, each are considered a collaborative opportunity.
- Several goals are suited for graduate research and collaborative opportunities with various universities..

7. Areas Not Addressed by This Roadmap

This roadmap does not fully evaluate or address the beneficial aspects of electrical distribution systems with respect to wildlife or evaluate potential secondary impacts such as radiation, construction impacts, or hazardous materials impacts.

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Appendix A
Current Status of Programs

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

Current Status: California

PG&E and Edison

- Both PG&E and Edison are developing risk assessment models that incorporates risk, habitat, and pole configuration factors. These models are being designed for prioritizing remediation.

Current Status: Regional and National

Colorado State University

- The College of Natural Resources at Colorado State University is currently conducting a study to monitor the effectiveness of modifications made to prevent raptor electrocutions.

Appendix B
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 products on the market do you view as the most and least promising to prevent electrocutions?
8. If working for a utility, what would you estimate the costs of power outages from bird electrocutions cost your company annually?
9. Other than birds, what wildlife-related electrocutions and outages are problematic?

Questionnaire Recipients

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

Appendix C

Short-term Avian Electrocution Roadmap Research Goals Summary

Title	*Description*	*Potential Stakeholders*	*Success Factors*	*Est. Cost*	*Potential Cost-sharing*
Standardizing Mortality Estimation	Using the Avian Electrocution Mortality section of the PIER Roadmap as a guide, develop a standardized approach to field estimation of avian electrocution mortality by measuring and consistently applying bias factors and detection methods.	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
Electrocution Risk Assessment	Based on the experimental design developed by Janns and Ferrer (1999) and others, conduct field and control trials of pole designs determined hazardous in APLIC (1996) to assist in identifying and ranking the mortality risk of each design. The results could be used to help prioritize remedial actions along distribution lines that incorporate several different design components.	PG&E, SCE, WAPA, EPRI, DFG, USFWS, APLIC	Adequate funding to develop trials and controls under wide range of conditions.	$200,000	PG&E, SCE, Industry
Conduct Risk Reduction Research	Growing evidence suggests current risk reduction methods and techniques may not be as effective as once thought and, in some cases, may increase electrocution risk. Fund research and development of new devices and techniques which can be cost-effectively implemented in the field to reduce electrocution risk.	PG&E, SCE, WAPA, EPRI, DFG, USFWS APLIC, Industry	Adequate funding to develop and evaluate new devices and techniques.	$1,000,0 00	PG&E, SCE, USFWS, DFG, Industry
Develop a Risk Assessment Model	Based on the research results from above, develop and test a risk assessment model that incorporates the entire range of physical and biological factors identified in this roadmap.	PG&E, SCE, WAPA, EPRI, DFG, USFWS APLIC, Industry	Adequate funding to develop and evaluate model parameters.	$75,000	
Develop and Support Updated Training Courses	Support continued development and refinement of training courses to teach the concepts, regulations, and techniques described in APLIC's *Suggested Practices*… for reducing bird electrocution events.	PG&E, SCE, WAPA, EPRI, DFG, USFWS APLIC, Industry	Participation by industry in the training courses.	$200,000	Industry
Develop Standardized Distribution Line Monitoring Protocol	Assessment of electrocution risk has been hampered by data which are often collected inconsistently. A standardized, comparable approach is needed to accurately determine relative risk and identify problem poles and structures. Develop a standardized monitoring protocol which incorporates pole design, environmental, and physical factors.	PG&E, SCE, WAPA, EPRI, DFG, USFWS, APLIC	Consensus among industry, agency, and regulatory researchers and managers on definition of "adequate" monitoring.	$45,000	Industry, USFWS, DFG
Revise and Update Mitigating Avian Electrocution	Recent advances in mitigating electrocution, monitoring distribution lines, prioritizing remediation actions, and mitigating effects should be captured in updates and revisions to the APLIC 1996 document.	PG&E, SCE, WAPA, EPRI, DFG, USFWS, APLIC	No apparent impediments to success except funding.	$50,000	PG&E, SCE, Industry

Title	*Description*	*Potential Stakeholders*	*Success Factors*	*Est. Cost*	*Potential Cost-sharing*
Publication					
Support Development of "Bird Safe" Regulatory Guidelines	Support the development of raptor safe construction and operation guidelines substantially in the form of those described in the California Public Utility Commission's (CPUC) General Order No. 95. These guidelines could then be adopted by the CPUC and incorporated in industry business practices as standards.	PG&E, SCE, WAPA, EPRI, DFG, USFWS APLIC, Industry	Participation by industry	$50,000	
Develop a System-Wide Data and Information Clearinghouse and Scope Reporting Requirement Policy Needs.	Assessment of electrocution risk in California will not be possible unless the regulatory community, industry, and researchers cooperate to promptly and accurately report electrocution events. Prepare a scooping study outlining policy needs and identifying potential impediments to implementation. Currently, published and unpublished reports and data are housed within industry and researcher files and are largely unavailable for use. Develop a clearinghouse for data and information to provide standardized information in an accessible and organized system	PG&E, SCE, WAPA, EPRI, APLIC, Industry	Study design consensus and cooperation of industry in carrying out study. Sensitive nature of known high-priority remediation sites.	$95,000	PG&E, SCE, Industry