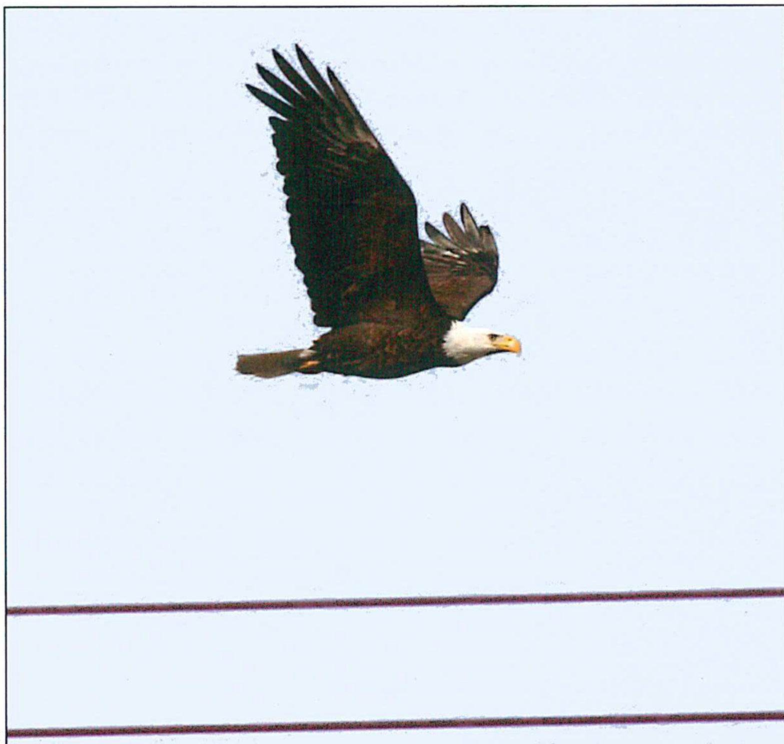

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FIGURE 3.5: Bald eagles are protected under the Bald and Golden Eagle Protection Act and the Migratory Bird Treaty Act.

otherwise lawful activities but who can work with the USFWS to develop and implement advanced conservation practices (ACPs). ACPs are defined as "scientifically supportable measures that are approved by the Service and represent the best available techniques to reduce eagle disturbance and ongoing mortalities to a level where remaining *take* is unavoidable" (50 CFR 22.3).

The regulations are intended to provide a mechanism—under carefully considered circumstances—where non-purposeful *take* of bald and golden eagles can be legally authorized. How-ever, BGEPA provides the Secretary of Interior with the authority to issue eagle *take* permits only if it is able to determine that the *take* is compatible with eagle conservation. This must be "…consistent with the goal of increasing or stable breeding populations."

Regulation establishes the issuance of permits for removing eagle nests where (1) necessary to alleviate a safety emergency to people or eagles, (2) necessary to ensure public health and safety, (3) the nest prevents the use of a human-engineered structure, or (4) the activity or mitigation for the activity will provide a net benefit to eagles (50 CFR 22.27). Only inactive nests may be *taken* except in the case of safety emergencies. Inactive eagle nests are defined by the continuous absence of any adult, egg, or dependent young at the nest for at least 10 consecutive days leading up to the time of *taking* the nest.

Special Purpose or Salvage or Miscellaneous Permit

In compliance with federal regulations, utilities may need certain permits to handle or "possess" injured or dead birds found along power lines. Salvaging and possessing carcasses of birds protected under the MBTA requires a Federal Special Purpose or Salvage or Miscellaneous Permit (50 CFR 21.27). This permit allows the burial or incineration of migratory birds found dead on a utility property or temporary possession for transporting to a suitable disposal location, rehabilitation facility, repository, or wildlife pathology laboratory. Permit conditions may vary but if the bird is a federally endangered or threatened species or eagle, most permits require the USFWS to be notified within 48 hours of discovery of the carcass. Depending on permit requirements, a quarterly and/or an annual report must be submitted to the USFWS regional permit office.

Endangered Species Act Consultation, Incidental Take Permit (ITP), and Habitat Conservation Plan (HCP)

When utilities propose the construction of, for example, power generation or transmission facilities where a federal nexus exists (i.e., on federal lands, with federal funding, or requiring federal authorization or permits), they must first consult with the USFWS through Section 7 of the ESA if any threatened or endangered species may be at risk. Before initiating an action, the federal agency owning the land or providing the funding or the non-federal permit applicant (e.g., an electric utility) should ask the USFWS to provide a list of threatened, endangered, proposed, and candidate species and designated critical habitats that may be present in the project area. The USFWS has developed a handbook that describes the consultation process in detail (USFWS and NMFS 1998). Based on a Biological Assessment, an ITP may be issued under Section 7 of the ESA.

When non-federal activities (i.e., lacking a federal nexus) will or may *take* threatened or endangered species, an ITP is required under Section 10 of the ESA. Approval of an ITP issued in conjunction with an HCP requires the Secretary of the Interior to find, after an opportunity for public comment, that among other things, the *taking* will be incidental and that the applicant will, to the maximum extent practicable, minimize and mitigate the impacts of such *taking*. An HCP must accompany the application for an ITP. The HCP associated with the permit is to ensure that conservation measures are adequate for avoiding jeopardy to the species or adversely modifying critical habitat. Information about consultations and HCPs can be obtained by contacting the local USFWS Ecological Services field office.

CANADA

Both MBCA and SARA provide for permitting and authorization of incidental *take* of migratory birds and species at risk. However, for MBCA, the Canadian government, through the CWS, has declared that they will not develop the permitting system; instead they recommend that companies use due diligence to prevent incidental impacts to migratory birds through best management practices.

SARA does provide for incidental harm to a species or destruction of its critical habitat under carefully controlled circumstances provided the activity does not jeopardize the survival or recovery of the species. These provisions include permits (three-year duration) or agreements (five-year duration). These authorizations are tied to strictly prescribed conditions. The government continues to work with stakeholders to develop operational policies to better implement SARA.

The requirement to protect critical habitat for migratory birds only applies in federal lands such as national parks, national wildlife areas, and bird sanctuaries. For critical habitat located in federally protected lands, the prohibition on destruction of this habitat applies automatically once the Environment Minister posts a description of the critical habitat in the Canada Gazette (typically within 90 days after the recovery strategy/action plan is posted to the SARA Public Registry).

The Environment Minister can recommend that the Cabinet protect a migratory bird species and/or the critical habitat of a species not on federal land if there is reason to believe the province or territory is not sufficiently protecting the species. However, the decision by the Cabinet to order protection is discretionary. There is also a species and habitat harm exemption clause in SARA for activities that have been authorized by other permits or agreements. This clause has not been implemented to date (2012).

CHAPTER 4

Understanding Bird Collisions

IN THIS CHAPTER

Understanding the nature of bird collisions is essential for minimizing and mitigating them. This chapter presents what is known about bird collisions including the susceptibility of certain species, variability in reported mortality rates, biological significance of collision mortality, and the biological, environmental, and engineering factors that influence collision risk.

Some bird species have a greater collision risk than others. Because of the need for power lines to deliver electricity, engineering design requirements, and potential interaction of birds with power lines, collisions cannot be eliminated, but they can be reduced. The understanding of bird collisions has grown since 1994 and revolves around the following principles:

- Exposure to collisions is largely a function of behavior. Specific behaviors (such as flushing, courtship displays, and aerial hunting) may distract birds from the presence of power lines.
- Exposure is increased for birds that make regular and repeated flights between nesting, feeding, and roosting areas in proximity to power lines.
- Susceptibility to collisions is partially a function of wing and body size and vision. Larger, heavy-bodied birds with short wing spans and poorer vision are more susceptible to collisions than smaller, lighter-weight birds with relatively large wing spans, agility, and good vision.
- Environmental conditions (such as inclement weather and darkness) may distract birds from the presence of power lines or obscure their visibility.
- Engineering aspects, including design and placement, can increase or decrease the exposure for collisions.

SUSCEPTIBILITY OF BIRDS TO POWER LINE COLLISIONS

Summaries of studies on birds' susceptibility to collisions have primarily come from Europe (see Bevanger 1998; Janss 2000; Rubolini et al. 2005). Based on the Bevanger (1998) summary of risk, the orders of birds reported to be most susceptible to collisions included:

- Gaviforms (e.g., loons)
- Podicipediformes (e.g., grebes)
- Procellariiformes (e.g., shearwaters, albatross, petrels)
- Pelecaniformes (e.g., pelicans, cormorants)
- Cicioniformes (e.g., storks, ibis, herons)
- Anseriformes (e.g., ducks, geese)
- Falconiformes (e.g., hawks, eagles)
- Galliformes (e.g., grouse)
- Gruiformes (e.g., rails, cranes)
- Charadriformes (e.g., gulls, terns)
- Apodiformes (e.g., swifts)
- Columbiformes (e.g., pigeons, doves)
- Strigiformes (e.g., owls)
- Passeriformes (e.g., song birds)

The reasons for this susceptibility are functions of species characteristics, in particular the birds' body size, weight, wing shape, flight behavior, and nesting habits (see *Biological Characteristics Influencing Avian Collision Risks* on page 36). For example, literature shows that, in general, birds of prey are good fliers, have the ability to avoid obstacles, and are not prone to collisions. It is when they are engaged in certain activities (e.g., territorial defense, pursuing prey) that their collision risk increases (see Harness et al. 2003; Olendorff and Lehman 1986).

IDENTIFYING COLLISION MORTALITY

Reporting bird injuries and mortalities is part of the U.S. Fish and Wildlife Service (USFWS) permit requirements (see Chapter 3) and permits are an element of utility Avian Protection Plans (APPs; see Chapter 7). In order to report mortalities correctly, the affected species and the cause (collision or electrocution) needs to be properly identified. Field guides can be used to identify the bird species, and a guide for identifying raptor remains is also available (CEC 2005). The U.S. Geological Survey's National Wildlife Health Center also provides information and technical assistance for identifying bird carcasses (USGS 2011). See Appendix E for resources.

Table 4.1 lists the typical damage evident in bird carcasses from collision injuries. Electrocution injuries often occur as burn marks on the feathers and feet (see APLIC 2006). Collisions can also lead to electrocutions

TABLE 4.1: Typical evidence of bird injuries or mortalities from power line collisions.*

Evidence	Description
Predominant bone fractures	Fractured wings, legs, shoulder bones, vertebra, or skull; torn off limbs
Damage to plumage	Mechanical damage, such as torn off or broken feathers
Skin injuries	Skin torn open or off, and open muscle, sinew, and bone tissue visible; power line may leave imprint in skin where the bird struck the line; necropsy may reveal internal bleeding and bruising
Secondary damage to extremities	Limited areas of infection at open wounds, bones, sinews, and muscles
General condition of injured birds	State of shock; handicapped by injuries and secondary damage

* Source: Adapted from BirdLife International (2003)

(called collision-electrocutions) if the bird's size is sufficient to make simultaneous contact with two phase conductors or with a phase conductor and grounded equipment, or if the collision causes two lines to slap together or get close enough to cause an electric arc.

VARIABILITY IN REPORTED MORTALITY RATES

It is difficult to extrapolate collision risk from one study and apply it to other power lines or compare it with other studies because of site-specific conditions and varying study methods and metrics. Likewise, many collision studies have been conducted in high risk areas and would not be applicable to lower risk areas. Numerous authors have summarized collision mortality with power lines (e.g., Faanes 1987; Bevanger 1998; Alonso and Alonso 1999; Rubolini et al. 2005; and Jenkins et al. 2010) and report mortality rates ranging from no birds killed to several hundred birds killed along a given segment of line per year. The California Energy Commission (CEC) study (Hunting 2002) provides a summary of collision mortality rates per unit area per distance. Reported mortality rates are highly variable and do not lend themselves to extrapolation to other lines because of site- and study-specific differences in:

- Species involved, such as ducks and sandhill cranes (*Grus canadensis*)
- Habitats, such as wetlands and agriculture
- Time periods and sampling regimes, such as single seasons versus multiple seasons
- Weather conditions, such as fog, wind, etc.
- Sampling biases, such as scavenger removal rates and searcher efficiency
- Types of power lines

Another limit to extrapolating bird/power line collision mortality estimates is the tendency to select worst-case scenarios as case studies (e.g., Koops 1987; Erickson et al. 2001; Manville 2005a). The CEC study (Hunting 2002) points out the difficulty in generalizing collision rates, and Bevanger (1999) provides an excellent summary of the

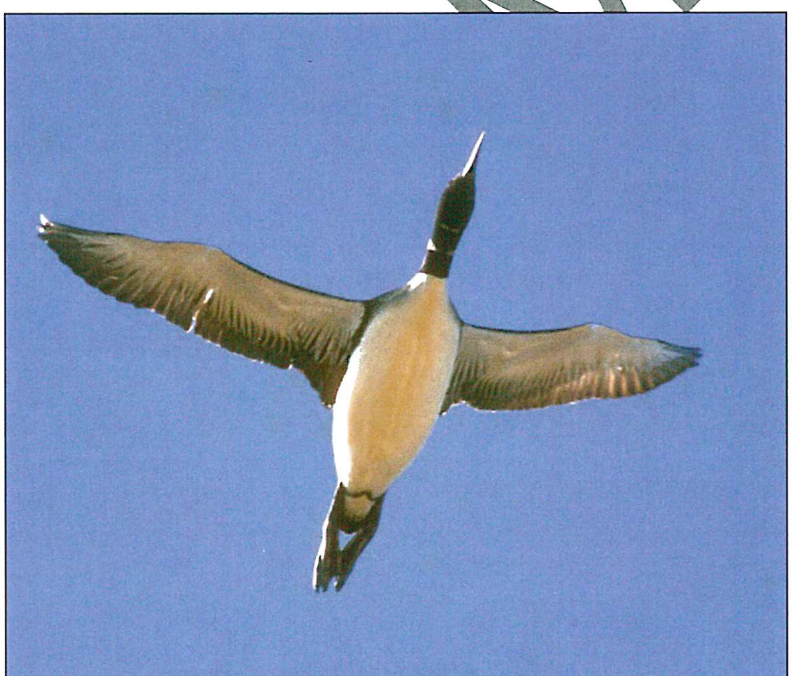

FIGURE 4.1: Collision risk is highly variable among species, with heavy-bodied birds, such as this common loon (*Gavia immer*), being more vulnerable because they cannot readily maneuver.

Bibliographies of Collision Literature

Appendix A of this manual includes the literature cited and a bibliography of collision literature. An annotated bibliography of early collision literature was provided by Avery et al. (1980). In addition, the California Energy Commission hosts a searchable database on collisions: *On-Line Annotated Bibliography of Avian Interactions with Utility Structures* (CEC 2011).

methodological issues in calculating these rates. For example, Faanes' (1987) calculation of 125 collisions/kilometer(km)/year (0.62 miles[mi]/year) for a line near a North Dakota wetland with abundant waterfowl during migration periods has been referenced by others including Bevanger (1999) and Erickson et al. (2005). Janss and Ferrer (2000) calculated collision rates of "one of the densest breeding populations of the great bustard (*Otis tarda*) in Spain," and for a large wintering population of common cranes (*Grus grus*) feeding in grain fields. Extrapolations from these studies could lead to exaggerated overestimates.

Adding to the difficulty in providing an overall assessment of collision mortality is that bird collisions do not usually cause power outages and consequently are not usually discovered. On the other hand, electrocutions are more likely to cause power outages and be reported (see APLIC 2006). To generate collision estimates for a particular power line, power line segments have to be selected randomly for mortality monitoring and should represent a diversity of habitats. Collision mortality can be relatively high or low depending upon the species, habitat, and the local circumstances. Appendix B provides recommendations for collision monitoring studies.

BIOLOGICAL SIGNIFICANCE OF COLLISION MORTALITY

Understanding the biological significance of collision mortality is necessary for developing proper reduction strategies. Collision mortality may have significance from social, wildlife policy, and biological points of view. Social and wildlife policy aspects relate to how the public and wildlife agencies consider collision mortality. The biological aspects relate to how the mortality affects bird populations. The social or wildlife policy assumption of significance is not necessarily biologically significant.

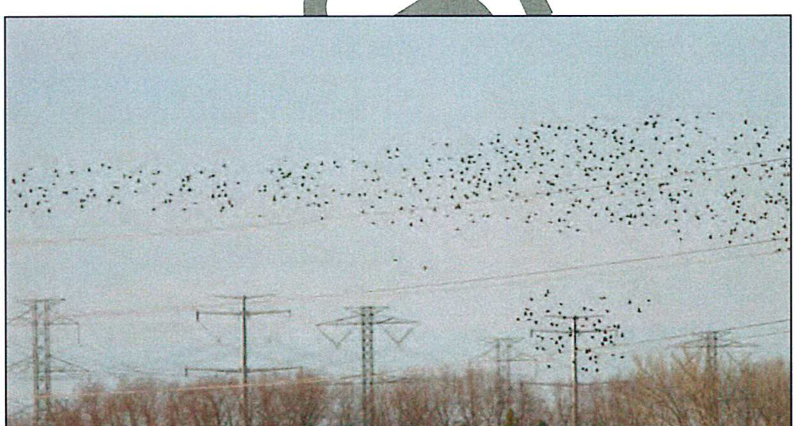

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FIGURE 4.2: Because of their higher reproductive rates, common bird species are generally at less risk of population effects from power line collisions.

From a biological perspective, significance evaluates whether collision mortality will affect the viability of a species' population. Biological significance results from an influence that significantly affects the ability of a species' population to sustain itself or increase its size.

This definition is used by population biologists to understand the influence of an adverse effect on a particular population or species. During site evaluation studies, utility biologists need to be aware of the possible impacts to rare species and to determine if the line would create a biologically significant risk as well as significant risk from a wildlife policy perspective (see Chapter 3).

Drewitt and Langston (2008) conclude that few studies of bird collisions with power lines show that collisions are biologically significant, which means individual losses from collision mortality are unlikely to affect large and robust populations. As an independent mortality factor, the effect of power line collisions on bird populations is generally thought to be compensated for in populations that have high reproductive rates (Bevanger 1998).

Biologically significant risk from collisions may occur in a population that is so small that the loss of a few individuals may impact local, rare, or endangered populations (Crowder 2000). Power line collisions may be significant to very small and/or declining populations, as they may not be capable of compensating for this loss (Bevanger 1998). Drewitt and Langston (2008) note that low reproductive rates and small populations of some species may further contribute to the likelihood of population effects. In addition, there are examples where collision mortality has occurred locally and concern has been expressed. Although not a federally endangered species, recent studies of sandhill cranes in Nebraska have shown that local populations can be affected by collision mortality (Murphy et al. 2009). Collisions during spring migration stopovers at major night roosts along the Platte River in Buffalo County, Nebraska, have been historically high near two 69-kilovolt (kV) transmission lines. The Newell's shearwater (*Puffinus auricularis newelli*), an endangered species in Hawaii, is an example of a species with a relatively small and restricted population that is threatened by multiple factors including power line collisions (Podolosky et al. 1998). Other threats include ground nest predation by dogs, cats, rats, pigs, and mongooses; collisions with buildings, cars, and other objects; and attraction to lights that may disorient them and cause them to fly around the light until they fall from exhaustion. Power line collisions appear to be a major contributor to the threats to Newell's shearwater's survival (Podolosky et al. 1998; Day et al. 2003; R. Podolosky, pers. comm.).

Outside North America, collision mortality is considered biologically significant for these species with low population numbers:

- Red-crowned cranes (*Grus japonensis*) in Japan (Archibald 1987, cited in Crowder 2000)
- Wattled cranes (*Bugeranus carunculatus*) in South Africa (Van Rooyen and Ledger 1999, cited in Crowder 2000)
- Capercaillie (*Tetrao urogallus*) in Norway (Bevanger 1995; Bevanger and Broseth 2004)
- Dalmatian pelicans (*Pelecanus crispus*) in northern Greece (Crivelli et al. 1988, cited in Drewitt and Langston 2008)
- Bonelli's eagle (*Aquila fasciata*) in Spain (Mañosa and Real 2001)
- Sarus crane (*Grus antigone*) in India (Sundar and Choudury 2005)
- Eagle owl (*Bubo bubo*) in Sweden (Herren 1969)
- Mute swans (*Cygnus olor*) in the United Kingdom (Kelly and Kelly 2005)

In the United States, collision mortality from power lines is considered biologically significant for two species with small populations: the whooping crane (*Grus americana*) and the California condor (*Gymnogyps californianus*).

WHOOPING CRANE

Losses of wild and reintroduced (or experimental) whooping cranes to power line collisions have been reported (Crowder 2000; Brown et al. 1987; Morkill and Anderson 1991; Stehn and Wassenich 2007). The one natural wild population, the Aransas-Wood Buffalo Population (AWBP), has been subjected to significant natural causes of mortality such that additional collision mortality is viewed as a threat to the species. The loss of 57 cranes (21.4% of the flock of 266) that died of starvation and infectious disease in the 12 months following spring 2008 (34 between spring and fall, 23 during the winter) was a serious setback (T. Stehn, pers. comm.). The additional loss of more than 10 birds per year for any reason could destabilize this species' recovery. However, the population has shown resilience with 279 whooping cranes at the Aransas National Wildlife Refuge in the spring of 2011 (T. Stehn, pers. comm.) compared to 247 in the spring of 2009.

FIGURE 4.3: The United States' population of endangered whooping cranes has had such significant mortality from natural causes that additional power line collision mortality is now viewed as a threat to the species.

The actual percentage of whooping crane mortality caused by collisions with power lines is hard to extrapolate for the AWBP because monitoring the small population during migration over such a large area (Figure 4.4)[10] is so difficult. In the 1980s, two of nine radio-marked juvenile whooping cranes in the AWBP died within the first 18 months of life as a result of power line collisions; that is 33% of total post-fledging losses (n = 6) of the radio-marked birds during the study (Kuyt 1992). Five of 13 known causes of mortality (38%) for the AWBP between April and November from 1950 to 1987 resulted from collisions with power lines (total mortality from all causes equaled 133 cranes) (Lewis 1992).

Collisions have been reported in other whooping crane populations as well. In the non-migratory Florida population, 20 out of 166 cases with known causes of mortality (12%) were from collisions with power lines, and in the migratory Wisconsin population, 3 out of 18 mortalities (17%) were from collisions with power lines (Stehn and Wassenich 2007). From 1950 to 2008, out of 508 fledged whooping cranes that have died, only 44 (8.7%) of the carcasses were recovered (C. Strobel, USFWS, unpubl. data). Of the 44 carcasses recovered, no cause of death could be determined for 17. Of the remaining 27 carcasses where a cause of death was established, 9 (33%) were from power line strikes and 18 (67%) were from other causes (e.g., disease, predators, and shooting).

[10] The whooping crane migration corridor is 322 km (200 mi) wide and extends 4,023 km (2,500 mi) from Wood Buffalo National Park in the Alberta and Northwest territories in Canada to the Aransas National Wildlife Refuge on the Gulf Coast of Texas (see Stehn and Wassenich 2007).

CALIFORNIA CONDOR

The federally endangered California condor was rescued from extinction when the last remaining wild individuals were captured from the mountains of southern California in 1987 to establish a captive breeding and reintroduction program. In 1991, reintroduction of captive-bred individuals began in select areas of the southwestern United States. As of December 2011, the total wild population of California condors was 210 individuals (NPS 2011). Reintroduced individuals from the captive breeding program have come into contact with power lines and collision mortality has occurred. For example, in a six-month period, three of eight condors that died in the wild died after colliding with power lines (D. Pearson, pers. comm.).

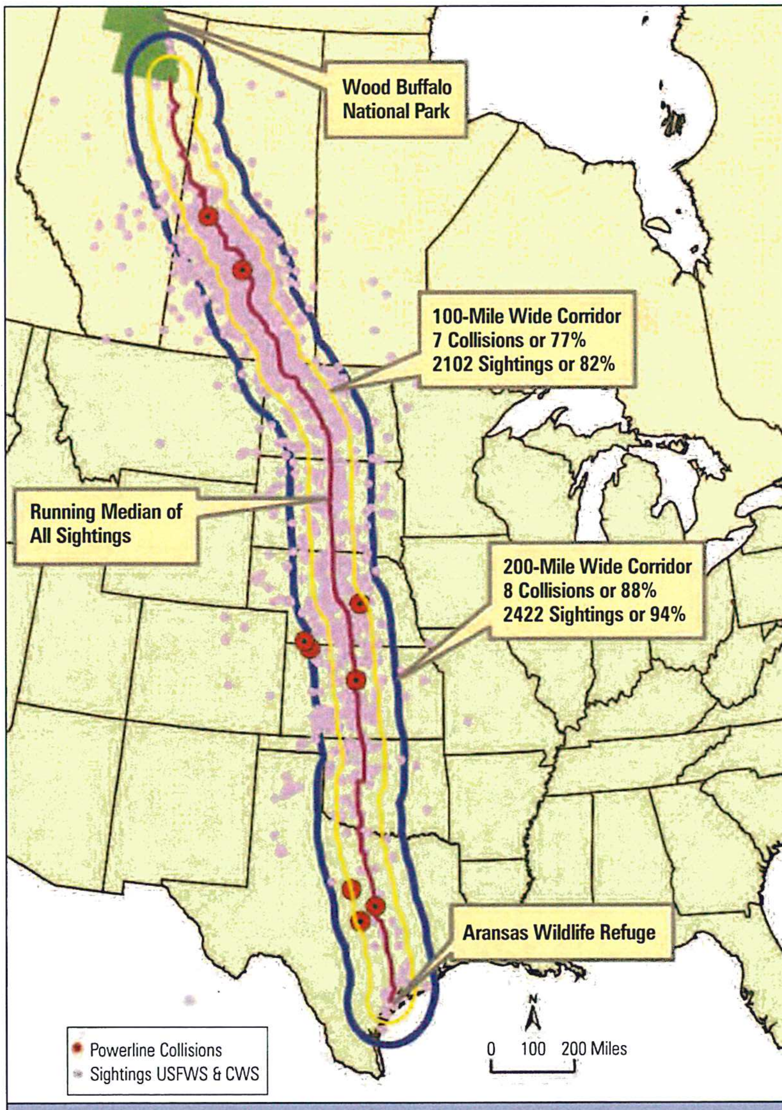

FIGURE 4.4: Whooping crane migration corridor in North America (2005 data from Stehn and Wassenich 2007).

FIGURE 4.5: Collision mortality has occurred with the expansion of the reintroduced population of the endangered California condor.

BIOLOGICAL CHARACTERISTICS INFLUENCING AVIAN COLLISION RISKS

Different bird species have different collision risks based on their biology, behavior, habitat use, and inherent abilities to avoid risk (e.g., Savereno et al. 1996) (see *Susceptibility of Birds to Power Line Collisions,* page 30). A number of biological characteristics influence the susceptibility of species to collisions with power lines:

- Body size, weight, and maneuverability
- Flight behavior
- Vision
- Age and sex
- Health
- Time of day and season
- Habitat and habitat use

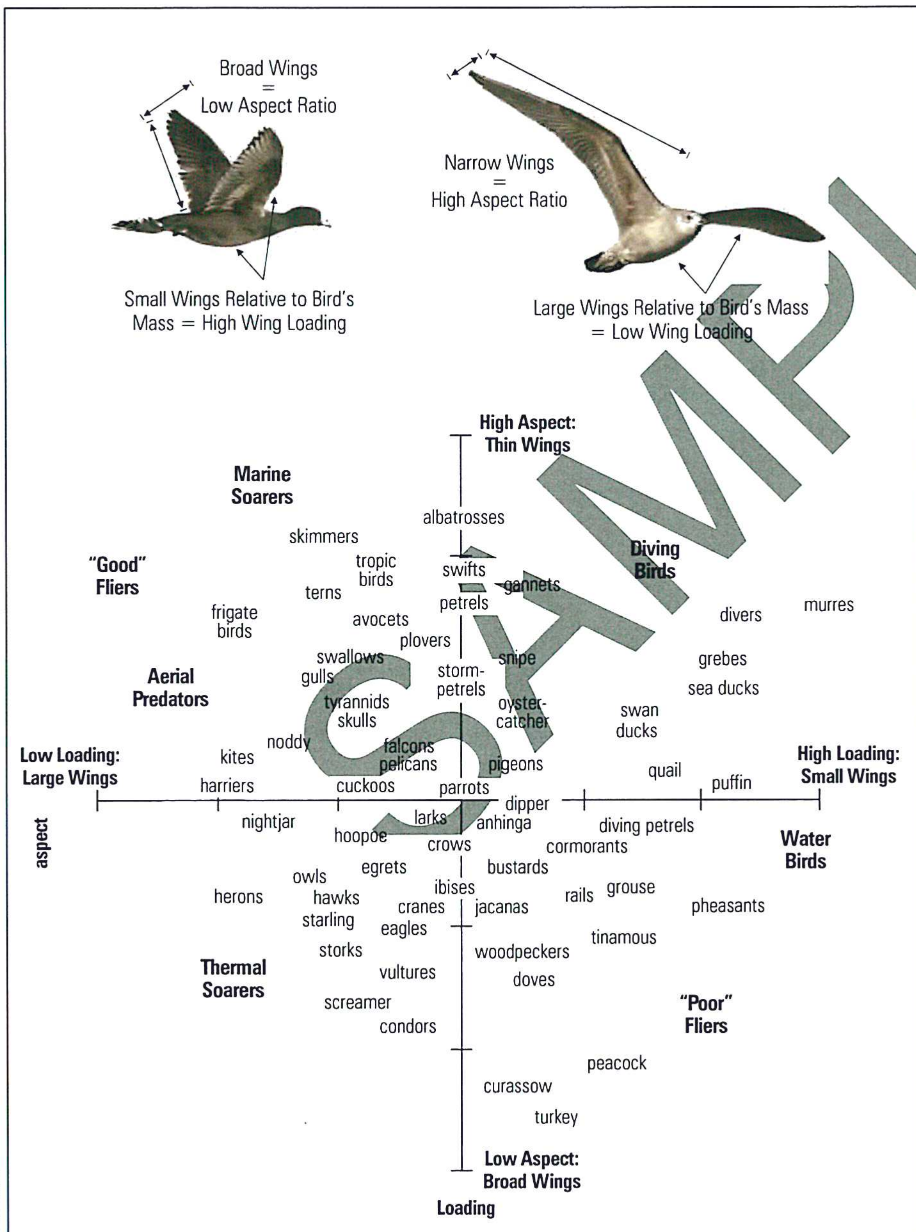

FIGURE 4.6: Wing loading and aspect ratio, among other factors, influence susceptibility to collisions (after Bevanger 1998).

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Knowing what avian species are involved, when they are present, and how they use the habitat along a power line route will help to estimate risk.

BODY SIZE, WEIGHT, AND MANEUVERABILITY

Several studies of collision vulnerability have addressed the relationship between bird size and maneuverability (e.g., Bevanger 1994, 1998; Janss 2000; Crowder and Rhodes 2002; and Rubolini et al. 2005). They classified birds based on weight and with these characteristics quantified wing loading (the ratio of body weight to wing area) and wing aspect ratio (ratio of the square of the wing span to the wing area) (Figure 4.6). Using Rayner's characterization (Rayner 1988), bird species were grouped according to the relationship of wing loading and wing aspect ratio and analyzed for collision susceptibility (Bevanger 1998). He developed six categories: poor flyers, waterbirds, diving birds, marine soarers, aerial predators, and thermal soarers. Bevanger (1994, 1998), Janss (2000), Crowder and Rhodes (2002), and Rubolini et al. (2005) have also evaluated different species and their collision susceptibility using wing loading and wing aspect ratio. They found in general that birds with high wing loading are more susceptible to collisions than birds with low wing loading; and that birds with low aspect ratios are more susceptible than birds with high aspect ratios. Birds with high wing loading and low aspect ratios represent poor fliers. Bevanger (1998), supported by Janss (2000) and Rubolini et al. (2005), also found this to be true.

High wing loading birds are frequently reported as collision casualties, including large, heavy-bodied birds with large wing spans such as herons (Mead et al. 1979), cranes (Walkinshaw 1956; Tacha et al. 1979; Brown et al. 1987), swans (Banko 1956; Beer and Ogilvie 1972), pelicans (Willard et al. 1977), and condors (D. Pearson, pers. comm.). These and similar species generally lack the maneuverability to quickly avoid obstacles.

Heavy-bodied, fast fliers are also vulnerable to collision. This characteristic is typical of most waterfowl, coots, rails, grebes, pigeons and doves, and many shorebirds (e.g., sandpipers and plovers). For example, waterfowl accounted for the majority of collision mortality at a site in the San Luis Valley, Colorado (Brown and Drewein 1995). Researchers have also noted that species with long legs and necks collide more often than those with more compact profiles (NUS Corporation 1979, unpubl., cited in Hunting 2002).

In comparison, terns with low wing loading and smaller body size are considered agile fliers and have a keen ability to avoid lines despite their high potential exposure. Henderson et al. (1996) found only two casualties beneath wires in a study of a common tern (*Sterna hirundo*) colony located within an industrial complex, where birds of all age classes and both sexes were making hundreds of flybys per hour (>10,000 flybys observed).

Body size and maneuverability do not explain all collision risk. Other factors can also contribute. For example, gulls and terns have low wing loading, yet they can be subject to collisions because of behavioral

FIGURE 4.7: Birds with high wing loading, such as swans, are more susceptible to collisions.

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characteristics, such as flocking, spending large amounts of time in the air, and flying at night. Although the low wing loading (light body) gives gulls and terns a more buoyant, graceful, and potentially slow flight speed, they are over-represented in Janss' mortality data set because of their large abundance at his study sites. This point is also made by Bevanger (1998) who cites observational studies by Meyer (1978), James and Haak (1980), and Beaulaurier (1981) to assert that gulls were 50 to 100 times less likely to collide with power lines when compared with ducks.

Passerines (songbirds) were reported in Bevanger (1998) to have a great deal of variation in flight morphology, yet most are not particularly heavy bodied or thin winged. Certain songbirds such as European starlings (*Sternus vulgaris*) may be so abundant that their representation among power line collision casualties may actually be attributed to abundance rather than susceptibility (Janss 2000). On the other hand, passerine carcasses are so small that they are much more difficult to discover and may be under-reported (Scott et al. 1972, cited in Drewitt and Langston 2008).

FLIGHT BEHAVIOR

Understanding the flight behavior of birds active near a power line can be useful in identifying the potential risk for collisions and how those risks might be reduced. The following flight behaviors have been reported in the literature (e.g., Drewitt and Langston 2008) as influencing collision risk:

- Flocking
- Flight altitude patterns of migrating and non-migrating birds
- Courtship, nest building, and feeding flights to and from and around the nest, especially for colonial species
- Flight ability of fledglings and juveniles
- Flights between nesting/roosting and foraging areas

Flocking species, such as waterfowl and wading birds, are more vulnerable to collisions than solitary species (Bevanger 1998; Crowder 2000; Crowder and Rhodes 2002; Drewitt and Langston 2008). The density of large flocks leaves little room to maneuver around obstacles; in fact, birds sometimes collide with each other when panicked (Brown 1993). Bevanger (1998) and Drewitt and Langston (2008), citing several studies, conclude that flocking behavior may lead to greater susceptibility, as trailing birds have obstructed views of an upcoming obstacle. Crowder (2000) and Crowder and Rhodes (2002) observed that flocks react to power lines at a greater distance from the line than do solitary birds. Scott et al. (1972) and James and Haak (1980) stated that flocking behavior was an important factor in starling collisions, as did Blokpoel and Hatch (1976) for snow geese (*Chen caerulescens*). A number of birds within large flocks of sandhill cranes were involved in power line collisions in the Platte River area, Nebraska; in several instances collisions of some birds within flocks were observed (Murphy et al. 2009).

FIGURE 4.8: Flocking species, such as these snow geese, can be more vulnerable to collisions.

Flight altitude is a function of species and environmental conditions such as winds, thermal conditions, visibility, precipitation, and time of day, as well as the type of flight (Newton 2008). Two types of bird flight altitude are observed: migrating or non-migrating.

Migrating birds take advantage of thermals and stronger tail winds when conditions permit, allowing them to conserve energy (Newton 2008) while staying well above power lines. In general, flight altitudes of migrating birds range from a couple hundred meters (m) (several hundred feet [ft]) to more than 6,000 m (20,000 ft). Weather conditions (e.g., wind speed and direction) influence flight altitude of migrants (see *Weather Conditions and Visibility*, page 48). Most transmission towers in the United States range from 15.2 m (50 ft) to less than 60.9 m (200 ft)[11] high depending upon design and voltage. If a

[11] Some structures exceed 61 m (200 ft) in height especially at river crossings and to clear other lines that might otherwise intersect (M. Schriner, pers. comm.; D. Bouchard, pers. comm.).

bird's flight altitude is at or below the height of power lines, collision risk can increase.

There are two basic types of migrating birds: long distance and daily migrants. Long distance migrants can fly thousands of kilometers (miles) without stopping and will have the least exposure to power lines during migration (e.g., some shorebirds, swallows, swifts, and terns). Most long distance migrants migrate at night, resting and feeding during the day (Manville 2007a). Daily migrants take shorter flights and make numerous stops to rest and feed (Newton 2008). Daily migrants include cranes, ducks, geese, and raptors. If power lines are in their landing or take-off paths, collision risk increases.

For non-migrating birds, flight altitude is likely to be within the range of power line height. Their flight is a function of their feeding, reproductive, and foraging behaviors. These behaviors usually occur within approximately 200 m (660 ft) of the ground, which can expose birds to collision risk when in the proximity of power lines. For predatory birds, the exposure to collision risk can be related, in part, to the pursuit of prey. Bevanger (1994) suggests that aerial hunters such as swifts, swallows, and certain raptors, such as the peregrine falcon (*Falco peregrines*), golden eagle (*Aquila chrysaetos*), and goshawk (*Accipiter gentilis*), typically have excellent maneuverability and very good vision. Yet because they chase prey at high speeds, the presence of a power line may not be perceived soon enough to avoid a collision with it.

Flight related to nesting behavior can increase collision risk if nests occur in close proximity to power lines. Such behavior includes courtship (e.g., aerial displays and pursuit), nest building, fledgling flights, feeding flights to and from the nest, territorial defense, and general flying around the nest or colony. These behaviors are most important

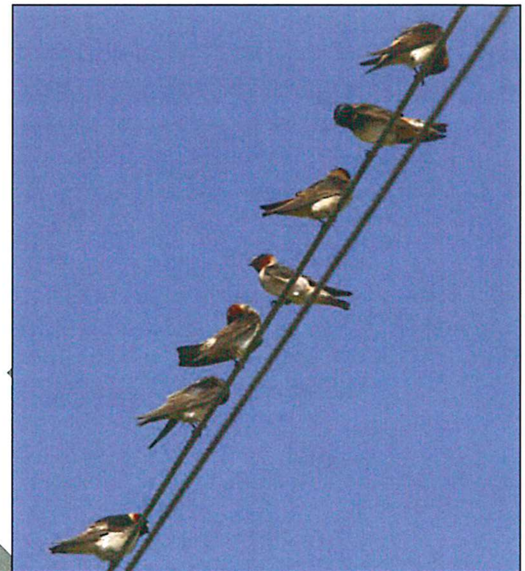

FIGURE 4.9: Aerial hunters that forage in flight within a couple hundred meters (several hundred feet) of the ground, such as swallows, can become collision victims.

for birds that nest in colonies, such as herons and egrets. Risks can also be associated with the age of a bird (i.e., adults and juveniles). Older birds are often acclimated to the presence of a line and will exhibit lower collision risk through well-developed flight patterns. Fledgling birds have less control of the flights and are more vulnerable to collisions than adults (see *Age and Sex*, page 41). There may also be risks for birds crossing a power line from the nesting site to a foraging area. Again, this is most important for colonial birds that will travel together to feed (see also *Habitat and Habitat Use*, page 44). Collision risks to foraging birds will occur when birds departing from and returning to a colony have to cross power lines. Their risk will be a function of the direction of foraging flights and the frequency of crossings. Mojica et al. (2009) reported 21 bald eagle (*Haliaeetus leucocephalus*) mortalities attributed to power line collisions in a study in Maryland conducted from 1985 to 2007.

VISION

Information on the visual acuity of birds relative to power lines is generally lacking (Bevanger 1998). However, when they are able to see power lines, birds do exhibit avoidance behavior. The use of line marking devices that increase the visibility of lines has confirmed this (see Chapter 6).

For birds, detecting power lines depends on the visibility of the wires and on the characteristics of their vision. Compared to humans, the frontal vision of many bird species is not high-resolution, and many species mainly use their lateral vision to detect details (Martin 2011). Birds often tend to look downwards when in flight (e.g., to look for conspecifics [their own kind] or food), which for some species puts the direction of flight completely inside their blind zone (Martin and Shaw 2010; Martin 2011; CMS 2011a).

Some birds have highly developed vision that they use to capture prey and avoid predators (Gill 1995). The eyes of most birds are on the sides of their heads, which allows them to see things on each side at the same time as well as in front of them. This wide field of vision enables birds to spot predators and obstacles. However, widely spaced eyes can make judging distances and depth perception more difficult, except in the area where the eyes' fields-of-view overlap.

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FIGURE 4.10: Swans' poor frontal vision, along with their large size, increases their susceptibility to collisions.

In addition, birds have blind spots caused by the length, width, and position of their bills. For some species, depending upon the size and movement of their bill, these blind spots can reduce the visual field. Researchers have noted that swans' poor frontal vision makes them more susceptible to collision (Martin and Shaw 2010). Martin and Shaw (2010) provided evidence that some species, such as bustards and cranes, have extensive blind spots in the frontal hemisphere and that downward head movement (forward pitch) greater than 25 degrees and 35 degrees, respectively, can render them blind in the direction of travel. If this occurs, objects directly ahead of the bird may not be detected during flight regardless of the visual capacities of the bird's eyes or the size and contrast of the object.

Raptors' eyes are closer to the front of their heads, giving them binocular vision, which is important for making distance judgments while pursuing prey. Having depth perception also makes them less vulnerable to collisions than birds with eyes on the sides of their head.

Birds with eyes adapted to underwater vision, such as ducks, tend to be emmetropic (objects are in sharp focus) in water and slightly myopic (nearsighted) in air (Jones et al. 2007). This may affect their ability to detect small diameter wires as they approach them at high speeds. A red-breasted merganser (*Mergus serrator*) was observed colliding with a shield wire with no reaction prior to the collision, and other mergansers were observed flying within 30.5 cm (12 in) of the shield wire with no reaction (N. Turley, pers. comm.). These observations suggest that the mergansers were not aware of the wire, which indicates that vision characteristics may play a role in collision risk. Examples of other birds in this group with eyes adapted to underwater vision include loons, grebes, other diving ducks (buffleheads, scoters, and eiders), gannets, and kingfishers.

FIGURE 4.11: Because they are nearsighted and fly at high speeds, mergansers may be unable to readily detect small diameter wires as they approach them.

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Some species have the ability to keep objects at different distances in focus simultaneously. For example, they are able to scan the horizon while keeping the ground in focus during flight, regardless of changes in elevation. This is believed to be achieved by asymmetry of the lens and cornea about an optical axis (Jones et al. 2007). This results in the eye being emmetropic in some parts of the visual field (the lateral and upper lateral visual fields) and myopic in others (lower lateral visual fields). For prey species such as pigeons, these characteristics allow the bird to scan the horizon for predators and conspecifics while foraging for objects on the ground. This same ability is also found in quail and sandhill cranes (Jones et al. 2007), but is generally not possessed by raptors or other species that must capture mobile prey.

In the last two decades, research on avian vision has indicated that ultraviolet sensitivity is an important component of avian vision. Birds detect a wider bandwidth of light in the violet and ultraviolet (UV) spectrum (440 nanometers [nm] to 10 nm) than humans do. This difference in sensitivity may relate to many different aspects of bird behavior including prey detection, foraging, display and mating, navigation, and circadian rhythm (Hart et al 1998; Bennett and Thery 2007). Based on this research, UV materials have been applied to line marking devices to help birds detect hazards that otherwise would not be seen. However, these UV materials have not been systematically tested in collision studies.

Regardless of a bird's vision, environmental conditions such as inclement weather and the time of day (e.g., low light or dark) can reduce a bird's ability to see even marked power lines. A number of line modification and marking strategies can be used to reduce the effect of these factors (see Chapter 5 and Chapter 6).

AGE AND SEX

Age and sex have a species-specific influence on collision risk. Crowder (2000) cites numerous studies showing that juveniles are more susceptible than adults (Thompson 1978; McNeil et al. 1985; Brown et al. 1987; Crivelli 1988; Savereno et al. 1996; Mathiasson 1999) but also notes two examples where adults are more susceptible (Ogilvie 1966; Anderson 1978). Brown et al. (1987) and Morkill and Anderson (1991) demonstrated statistically that juvenile sandhill cranes collided with power lines more frequently than their proportion of the population would indicate. Conversely, Anderson (1978) found that adult mallards (*Anas platyrhynchos*) were more vulnerable to collisions than juveniles. Ogilvie (1966) suggested that age was not a factor in collision susceptibility for mute swans.

FIGURE 4.13: Endangered Newell's shearwater mortalities at a Kauai power line were mostly non-breeding adult and subadult birds.

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Many authors suggest that young birds or those unfamiliar with the area are more vulnerable than experienced birds (Anderson 1978; Thompson 1978; McNeil et al. 1985). The less-controlled flight of young birds also increases their collision risk. These birds are generally believed to be more susceptible to both electrocution and collision, though this may be confounded by the greater proportion of young birds in the population (Bevanger 1998). Most (11 of 14 = 78.6%) of Newell's shearwater collisions at a Kauai, Hawaii, power line were non-breeding birds, though many of those were likely subadults. The proportions of non-breeding adults and subadults in the population were not reported (Cooper and Day 1998). Juveniles of many migratory species are especially at risk because they have not yet encountered nor learned to avoid the assortment of risks they face.

FIGURE 4.12: Some juvenile birds, such as sandhill cranes, collide with power lines more frequently than their adult counterparts.

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Less information about the differing vulnerability of sexes exists because comparative data are rarely available. However, several studies have presented evidence that male ducks are more prone to collisions than females (Boyd 1961; Avery et al. 1977; Willard et al. 1977; Brown and Drewien 1995). The courtship and pursuit behaviors of male ducks greatly increase their frequency of local flights and can distract them from seeing and avoiding power lines. Distractions for other species also include pursuit of mates, competitors, or prey, which can increase collision risk (Willard et al. 1977; Anderson 1978).

HEALTH AND CONDITION OF THE BIRD

Studies of birds killed by power line collisions indicate that poor health may increase collision risk. Mute swans with elevated blood lead levels had higher collision risk than did healthier birds (Kelly and Kelly 2005). Low weight swans and swans with heavy burdens of toxins were over-represented among swans killed by collisions in Sweden (Mathiasson 1999).

The ability of the bird to maneuver can also be impaired by entanglement with fishing lines and other anthropogenic materials. Manville (2005b) reported on entanglement issues involving Canada geese (*Branta canadensis*) and other waterbird species with six-pack beverage rings and monofilament fishing line, along with plastic debris ingestion, all of which may increase their susceptibility to power line collisions due to weakened conditions, altered aero-dynamics, and impaired health.

Collision mortality can also lead to health effects in populations of birds. In rare instances, collisions that occur in high enough numbers can indirectly contribute to some diseases, such as botulism. Malcom (1982) reported the deaths of several thousand grebes and ducks from botulism that were initiated by the victims of collisions with a transmission line in south central Montana. The collision victims fell into a wetland where their carcasses provided the energy substrate in which dormant *Clostridium botulinum* spores became active. These bacteria produce a toxin that invertebrates consume and concentrate without ill effects. Those toxin-laden invertebrates (e.g., fly-egg-maggot) become food for other ducks and a vicious cycle can develop and become protracted (Rocke and Friend 1999), much as Malcom observed.

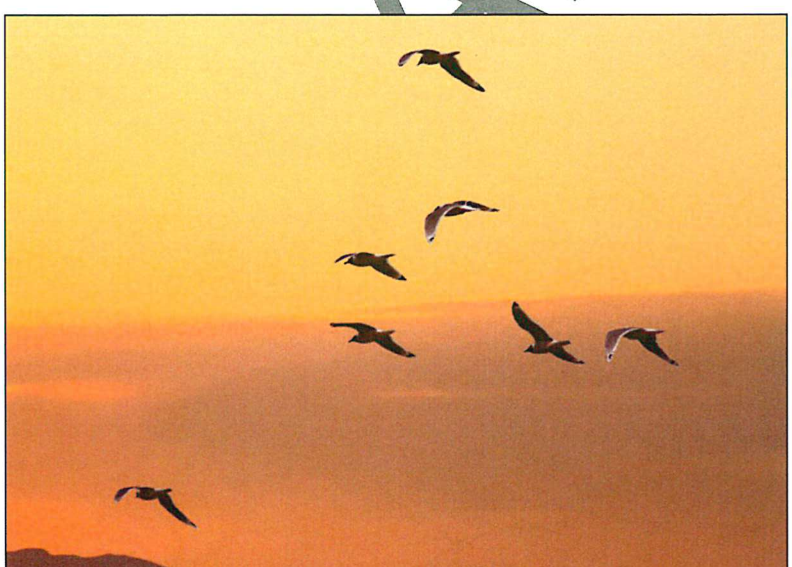

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FIGURE 4.14: Gulls (pictured) and waterfowl tend to make feeding flights at dusk and dawn, when reduced light increases collision risk.

TIME OF DAY AND SEASON

Time of Day

Studies have shown that time of day is important to collision frequency in daily flights and during migration. Different species generally feed at different times of day. Non-breeding birds, including migrating species, generally feed continuously during the day and are considered to have continuous exposure to power lines in the vicinity of their feeding areas. When birds are nesting, they often show a periodicity in feeding.

Collisions are much more likely during the night than the day (Scott et al. 1972; Krapu 1974; Anderson 1978; and James and Haak 1980; all cited in Crowder 2000; Pandey et al. 2008). Gulls and waterfowl tend to make feeding flights after sunset and before sunrise. Many waterbird species regularly fly at night in response to tidal cycles or prey activity (Black and Collopy 1982; Erwin 1977; Robert et al. 1989; Dodd and Colwell 1998) or predator avoidance. Inability to see the wires due to low light conditions probably raises the collision risk for these species (Scott et al. 1972; Krapu 1974; James and Haak 1980; Brown and Drewien 1995). At the San Luis National Wildlife Refuge Complex in California, bird flight diverters were effective on waterfowl but not on coots, which authors attribute to the fact that coots fly at night and cannot see the diverters (Ventana Wildlife Society 2009).

Species that migrate at night, such as songbirds and herons, may be vulnerable to collisions if weather forces them to fly at low altitudes. However, generalizing from one species to another or one habitat to another that nocturnal flight behavior may be more risky than diurnal flight behavior needs to be cautioned. Deng and Frederick (2001) investigated nocturnal bird flights of wading birds in the vicinity of a 550-kV transmission line adjacent to the Everglades in south Florida. They observed nine species of wading birds including herons, egrets, and wood storks (*Mycteria americana*). The investigation showed that nocturnal-flying wading birds were less responsive to the power lines than diurnal-flying birds; however, the birds generally flew higher over the power lines at night than during the day. No collisions were observed but the authors stated that the sampling period was short (118 hours). One of the suggested reasons for the lack of collisions was that the birds were acclimated to the presence of the line.

Similarly, radar data collected by Harmata et al. (1997) along the Missouri River indicated that birds flying at night flew at heights well above power lines. By flying higher at night, waterbirds and other species may lower collision risk with natural and anthropogenic obstacles. However, there may be risks from lines that occur in the departing and arriving zones for roosting or foraging habitats. For example, dark-rumped petrels (*Pterodroma phaeopygia*) and Newell's shearwaters in Kauai, Hawaii, crossed much closer to power lines in morning seaward flights than in evening landward flights, and all recorded Newell's shearwater collisions occurred during morning flights (Cooper and Day 1998).

Season

Seasonal bird abundance is also correlated with collision mortality. For example, seasonal flight behavior differences resulted in more wintertime collisions for ptarmigan in Norway (Bevanger and Broseth 2004). Migration seasons generally pose a greater risk to migrating birds because of both higher flyover frequency and unfamiliarity with local landscapes. The nighttime proportion of crane and waterfowl collision mortality versus total collision mortality was 31.8% in the fall (1990) during migration and 7.7% in the spring (1991) in San Luis Valley, Colorado (Brown and Drewein 1995).

Willard (1978) described a situation in the Klamath Basin, Oregon, that illustrates how both collision mortality and its population effects can increase during the breeding season. At Lower Klamath Lake National Wildlife Refuge, adult American white pelicans (*Pelecanus erythrorhynchos*) flew low over canals and collided with power lines while searching for food. For this species, this meant a double loss: first, the loss of the adult that collided with the line, and second, the loss of the young, which rarely fledge after one parent is lost because both parents must forage extensively to feed them.

HABITAT AND HABITAT USE

Power lines located near habitats with high avian use (such as nesting, foraging, roosting, and resting sites) may pose greater exposure to collisions for some species. For example, power lines between foraging and roosting sites of wading birds will be frequently crossed, which increases the collision risk potential. This is especially true when only a short distance separates the two habitats. Birds in these situations typically fly at low altitudes, potentially putting them at the height of power lines. Willard et al. (1977) suggested that overhead wires within a single habitat (e.g., within a wetland) are more likely to cause collisions than those between two habitats (e.g., wetlands and uplands); other studies have found the opposite to be true (e.g., Faanes 1987; Brown et al. 1987; Morkill and Anderson 1991).

PREVIOUS VIEW

The critical questions are how often, and in what numbers, do birds fly across a power line during their daily routines? For example, in a study in the San Luis Valley of Colorado, Brown et al. (1987) found that power lines dividing wetlands (used for roosting) from grain fields (used for feeding) caused the most collisions for sandhill cranes and field-feeding waterfowl. This occurred because these habitats encouraged the birds to cross the lines at low altitudes several times each day. However, the same power lines had little effect on diving ducks, which had restricted their activities to wetlands. Thus, the risk of a particular power line depends in part upon the way each species uses the adjacent habitat.

FIGURE 4.15: Power lines located between the foraging and roosting sites of wading birds, such as this white ibis *(Eudocimus albus)*, may result in higher collision risk.

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Power lines, including those that border habitat such as a wetland used by many birds, may present little risk if the adjacent habitat separated by the power lines is not attractive to birds (e.g., a city rail yard). Conversely, if the adjacent habitat is a grain field, collisions may result in fall and winter for field-feeding birds that make daily flights between wetland roosts and foraging sites, including sandhill cranes, Canada geese, mallards, and pintails (*Anas acuta*) (Thompson 1978; Brown et al. 1987; Morkill and Anderson 1991). The same line may represent lower risk during the breeding season when these birds remain in wetlands throughout the day. Although forested habitats located near power lines can

FIGURE 4.16: Research conflicts on whether or not overhead wires within a single habitat, such as this wetland, are more likely to cause collisions than those between two habitats.

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sometimes reduce collision risk (see *Managing Surrounding Lands* on page 58), in some forested habitats where there are open clearings for the power lines, collision risk may be higher for birds that fly across the open corridor while going between forested areas.

During migration, birds make stopovers in their preferred habitats. When migratory birds' staging, roosting, resting, and foraging areas are located near power lines, especially when ingress or egress coincides with inclement weather, collision risk increases (Manville 2005a, 2009a). This can be especially true when there are large concentrations of birds; for example, sandhill cranes that number in the tens of thousands along the Platte River in Nebraska (Murphy et al. 2009).

Some habitats, such as lakes and ponds, have seasonal use patterns. Proximity to shoreline habitat was linked to bald eagle collisions (21) and electrocutions (24) at Aberdeen Proving Grounds, Maryland (Mojica et al. 2009). Higher collision mortality was found at power lines near shorelines used as feeding areas. The 16,000 hectare (39,537 acre) area on Chesapeake Bay had 42 resident pairs and seven known communal roosts used by migrants from the north and south during the winter and summer months, respectively. In a high bird concentration area along Lake Ontario, double-crested cormorants (*Phalacrocorax auritus*) were the most commonly reported collision victim, although they were over-represented relative to their abundance in the area, and gulls and waterfowl were the next most commonly reported species to collide with lines (Barrett and Weseloh 2008). A PacifiCorp study calculated the distance of collision mortalities to the nearest water body using survey data collected in Oregon, California, Idaho, Utah, and Wyoming from 2004 to 2009 (S. Liguori, PacifiCorp, unpubl. data) (Table 4.2).

TABLE 4.2: Average distance of collision mortalities from nearest water body.*

Species	Sample Size	Average Distance
Snow goose *(Chen caerulescens)*	37	82.3 m (270 ft)
American white pelican *(Pelecanus erythrorhynchos)*	17	82.6 m (271 ft)
Tundra swan *(Cygnus columbianus)*	3	89.3 m (293 ft)
Sandhill crane *(Grus canadensis)*	7	119.8 (393 ft)
Great blue heron *(Ardea herodias)*	7	154 m (505 ft)
Mallard *(Anas platyrhynchos)*	5	213.4 m (700 ft)

* Source: PacifiCorp, unpubl. data

ENVIRONMENTAL CONDITIONS INFLUENCING AVIAN COLLISION RISKS

Environmental conditions that can increase the risk for collisions with power lines include:

- Land uses
- Weather conditions and visibility
- Sudden disturbances

The relative importance of these conditions varies with location, season, species, and different populations of the same species.

LAND USES

Land uses, such as conservation, recreational, residential, agricultural, and industrial, have habitats and management practices that can attract or discourage bird use. Collision risk depends on the location of power lines within these areas and the bird species that are drawn to them.

Conservation and Nature-Based Recreation Lands

Conservation areas and wildlife refuges vary greatly in size and habitat type and are often managed for specific types of wildlife and/or nature-based recreation uses. Many conservation lands have distribution lines that supply their power needs and may also be crossed by transmission lines. These lines may present collision risk depending on the habitats, species, and human activities present. The potential for disturbing and flushing birds into nearby power lines can be higher in recreation areas due to increased human activity or lower if resident birds are acclimated to human activity. Power lines that cross high avian-use habitats such as wetlands or are placed between foraging and roosting areas may also result in a higher risk of bird collisions (see *Habitat and Habitat Use* on page 44). Although a proposed power line route may not be able to avoid such conservation areas, managers need to be aware of the potential risks so they may be minimized (see Chapter 5).

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FIGURE 4.17: Power lines crossing agricultural fields with seasonally attractive crops or residue can contribute to collision risk for some flocking species, such as cranes, waterfowl, songbirds, and these trumpeter swans (*Cygnus buccinator*).

Residential and Urban Recreation Lands

Residential and urban recreation lands vary widely in their attractiveness to birds (e.g., Chace and Walsh 2006). Generally, urban recreation lands such as parks and golf courses are interspersed within or between densely populated residential areas. These lands often become habitat islands. For example, they may have small wetlands that are used by various protected birds. Distribution lines may be especially plentiful in residential and recreational areas and can pose a collision risk, depending on the susceptibility of the species, when situated in the flight patterns of birds.

Agricultural Lands

Agricultural fields and ponds can attract birds; for example, grain crops are seasonally attractive to many flocking species such as cranes, waterfowl, and blackbirds, along with rodents that attract raptors. Because grain fields are used only as feeding areas by these species, they may be attractive when they are in close proximity to nesting, roosting, or wintering habitat. Agricultural fields, especially those that are managed with burning or flooding or have nearby wetlands, can also attract a variety of bird species during staging and migration and may even result in shortstopping, i.e., drawing birds to these attractive sites for the winter rather than their historical wintering sites (Viverette et al. 1996). Collision problems may develop when birds must cross power lines to make daily, low-altitude flights between feeding areas and nesting or roosting sites. See also *Habitat and Habitat Use* (page 44).

Industrial Lands

Industrial lands sometimes provide attractive bird habitat. Gulls, vultures, crows, ravens, and other scavengers often gather at landfills in large numbers. Cooling ponds at electricity generation facilities, municipal sewage ponds, settling ponds at mines, and other industrial water bodies can attract waterbirds, shorebirds, and raptors. As with other types of land use, the degree of hazard posed by power lines will vary depending upon the proximity of the lines to these avian-use areas (see *Habitat and Habitat Use* on page 44). If bird collisions become a problem, property managers may be able to choose from a variety of options to modify or discourage bird use of the area (see *Managing Surrounding Lands* on page 58).

WEATHER CONDITIONS AND VISIBILITY

Weather conditions play a very important role in both the visibility of power lines and in the behavior of birds in flight during migration and local movements, such as daily foraging activity. When weather conditions interact with biological characteristics (e.g., flight behavior, wing loading and aspect ratio, and season), collision risk may be dramatically affected.

Adverse weather conditions, such as fog, dense cloud cover, high and variable wind speeds, precipitation, and reduced or zero visibility are associated with greater collision risk. Reduced visibility and high wind speeds can also cause birds to fly at lower altitudes, potentially putting them at the same height as power lines. The influence of weather on flight altitude was reviewed in depth by Shamoun-Baranes et al. (2006), and the effect of weather on flight height and behavior has been observed in many bird species (Drewitt and Langston 2008; Newton 2008).

Weather and biological factors are often interrelated and may affect flights within high bird-use areas. The timing of daily flights may subject certain species to adverse weather conditions associated with collisions, such as fog (Scott et al. 1972; Tacha et al. 1979) or wind (Brown 1993). This is especially true in coastal and low-lying areas that are frequently foggy or windy. When possible, birds will avoid flying in heavy precipitation or fog. Problems most often occur when birds unexpectedly encounter these conditions. Storms or fog can arise quickly and birds may collide with power lines when attempting to leave feeding areas for protected roosts (Wheeler 1966; Tacha et al. 1979). In foul weather, birds may be attracted to lighted areas on the ground (Manville 2007a). If power lines are also in or near those areas they could be in the landing approach of the attracted birds and become a collision risk (see *Lighting*, page 52).

Wind, wind shear, and turbulence most often appear to influence collisions when birds fly at power line heights. Some birds decrease flight altitude in high winds (Scott et al. 1972; Raevel and Tombal 1991). Poor conditions—wet feathers, precipitation, high winds, wind gusts, and turbulence—also hamper birds' ability to control flight and further increase collision risk (Walkinshaw 1956; Avery et al. 1977; Willard et al. 1977; Anderson 1978). In high-velocity winds, birds may collide with other birds, buffeting them into fully visible and familiar power lines (Brown et al. 1987; Morkill and Anderson 1991; Raevel and Tombal 1991; Brown and Drewien 1995).

In the San Luis Valley, Colorado, collisions occurred more frequently on days with winds >24 km per hour (15 mi per hour) (Brown and Drewein 1995). Collisions were also more likely with tailwinds, which increase a bird's ground speed, than with headwinds, which have the opposite effect (Savereno et al. 1996). Crowder (2000) reviewed older evidence of power line collisions resulting from stormy (Wheeler 1966), foggy (Tacha et al. 1979), or windy (Brown et al. 1987; Morkill and Anderson 1991) conditions. These studies showed that wind, especially associated with stormy weather, is an important contributor to collisions. It has been suggested that birds, such as gulls, with a high aspect ratio and low wing loading are more susceptible to being blown into lines than other bird

FIGURE 4.18: Birds usually initiate migration in favorable weather conditions, but when they encounter inclement weather they may decrease their flight altitude, which increases collision risk when power lines are present.

species without these physical characteristics (Bevanger 1998).

The impact of weather is also related to season, as adverse weather may pose a greater risk during migration (APLIC 2007) and can influence the initiation of migration (Shamoun-Baranes et al. 2010). Songbirds usually begin migration in favorable conditions, but may encounter inclement weather en route. The weather hazard may be worsened when migratory birds respond to fog and precipitation by decreasing their flight altitude (Gauthreaux 1978a) or by attempting to land (Manville 2007a). In known or historic staging, roosting, resting, feeding, or stopover areas for migratory birds located in immediate proximity to power lines, there can be a substantial increase in collision risk, especially when bird ingress or egress coincides with inclement weather (Manville 2005a, 2009a). This effect is magnified when flocks are very large, as with migrating sandhill cranes in the Platte River area of Nebraska (Murphy et al. 2009).

The flight altitudes of migratory birds can vary greatly and are strongly correlated with winds aloft, air clarity, turbulence, thermals, and weather, both day and night. In particular, thunderstorms and low cloud ceiling conditions are known to cause nocturnally migrating songbirds to land or to fly at lower altitudes that increase collision risk, particularly with illuminated structures (Winkelman 1995; Gill et al. 1996; Erickson et al. 2001; Johnson et al. 2002; Kerlinger 2003). Various radar studies have estimated that under normal weather conditions, 84% to 97% of nocturnally migrating songbirds fly at altitudes of 125 m (410 ft) or more above ground level where they are not exposed to risk of collision with power lines (Mabee and Cooper 2002; Cooper 2004; Mabee 2004).

SUDDEN DISTURBANCES

Sudden disturbance can panic and flush birds, especially flocks of birds, into nearby power lines and has been well documented as a contributing factor to collisions (Krapu 1974; Blokpoel and Hatch 1976; Anderson 1978; Brown et al. 1984; Archibald 1987). Birds may be flushed by vehicles, trains, pedestrians, aircraft, farm equipment, hazing, hunters, predators, etc., along ROWs and may collide with power lines in their effort to escape (APLIC 2007). Crowder (2000) reviewed older evidence of power line collisions resulting from sudden disturbance of geese by vehicles (Schroeder 1977) or airplanes (Blokpoel and Hatch 1976). One such disturbance resulted in a collision event with mallards during Crowder's (2000) field study. Murphy et al. (2009) support the idea that most sandhill crane collisions at Platte River, Nebraska, occur when closely congregated birds are flushed after dark. In Washington, roosting American white pelicans collided with an adjacent distribution line when flushed during the night by a passing train, even though line marking devices were installed (S. Liguori, PacifiCorp, pers. comm.).

ENGINEERING ASPECTS INFLUENCING AVIAN COLLISION RISKS

The following engineering aspects can influence the risk of collisions with power lines:

- Diameter of lines (shield wires versus phase conductors)
- Line placement (proximity to avian habitat)
- Line orientation (relative to biological and environmental factors)
- Line configuration (aligned vertically or horizontally and the number of lines)
- Structure type (guyed versus self-supporting)
- Lighting (steady burning versus blinking)

DIAMETER OF LINES

The smaller diameter of transmission line shield wires compared to phase conductors influences the risk of collisions, with shield wires being the lines most often involved (Scott et al. 1972; Willard et al. 1977; Brown et al. 1987; Faanes 1987; APLIC 1994; Savereno et al. 1996; Jenkins et al. 2010). Because of their smaller diameter (1 to 1.3 centimeters [0.4 to 0.5 inches]) compared to phase conductors (2.5 to 5 cm [1 to 2 in]) and their position above the phase conductors, shield wires are the least visible type of power lines and they are in the flight path of birds that gain altitude to avoid the more obvious phase conductors. The shield wire protects, or shields, the phase conductors from lightning strikes.

Distribution lines consist of phase conductors and a neutral wire, which is at the same level or below the phase conductors. Though it is not absolute, most birds gain altitude to avoid an obvious line, which implies that neutral lines are less likely to be involved in collisions.

LINE PLACEMENT

The proximity of power lines to bird take-off and landing areas can affect collision risk (Lee 1978; Thompson 1978; Faanes 1987), but no specific setback distance has been found in the literature. Brown et al. (1984, 1987) found that no sandhill crane or waterfowl collisions occurred where distances from power lines to bird-use areas were ≥1.6 km (1 mi). Faanes (1987) found that collision rates dropped off dramatically after 400 m (1,312 ft). Faanes (1987) stated that "among the sites I examined, power lines situated 400 m (1,312 ft) or more from the edge of the water generally had lower observed mortality than sites where the power line was within this distance." Quinn et al. (2011) found no bird carcasses under power lines that were situated more than 500 m (1,640 ft) from the edge of the water; at distances of 60 m (197 ft), collision mortality dropped off dramatically ($p = 0.0012$, $df = 3$). See also *Habitat and Habitat Use* on page 44. See Chapter 5 for examples of risk and reduced risk situations.

LINE ORIENTATION

Orientation of power lines relative to biological characteristics (e.g., flight behavior, season, habitat, and habitat use) and environmental conditions (e.g., topographical features and weather patterns) can influence collision risk. When planning power line routes, features that are traditional flight corridors, such as mountain ridges, river valleys, and shorelines, should be considered (Colson and Yeoman 1978; Faanes 1987). Power lines that parallel primary bird flight paths pose less risk than a perpendicular orientation (Crowder 2000; Scott et al. 1972; McNeil et al. 1985). For example, the perpendicular orientation of a line relative to a topographical feature poses a greater collision risk to local and migrating birds than a parallel orientation (see Figure 4.19).

Lines that are at or below the height of nearby trees rarely present a problem to small tree-dwelling birds because of their maneuverability; furthermore, large birds will gain altitude to fly over the tree line and consequently avoid the power line (Thompson 1978; Raevel and Tombal 1991). For example,

FIGURE 4.19: Orientation of power lines parallel to ridges or narrow, low altitude flyways presents a lower risk of collision than perpendicular orientation.

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a power line that crosses a narrow river bordered by trees that are taller than the line is likely to have a lower collision risk than lines crossing broad rivers because most birds will fly over the tree tops to cross the narrow river valley (CMS 2011a).

Strong tail winds can be detrimental to birds' ability to execute avoidance maneuvers. Brown (1993) suggested that north-south orientation of lines increased collision frequency for cranes and waterfowl in the San Luis Valley, Colorado, because birds crossing them on an easterly heading were often subjected to prevailing westerly winds. See also *Biological Characteristics*, on page 36, and *Weather Conditions and Visibility* on page 48.

LINE CONFIGURATION

Line configuration—phase conductors aligned vertically or horizontally, and the number of conductors—is a collision factor that intuitively makes sense, but there are too few studies to draw conclusions. Most researchers agree that keeping the vertical arrangement of multi-conductor transmission lines to a minimum is beneficial because it reduces the height of the collision zone. However, a single-pole vertical structure is often esthetically more acceptable and requires less ROW width.

Thompson (1978) and others (Bevanger 1998; Crowder 2000; Drewitt and Langston 2008) have suggested that clustering lines (i.e., several power lines sharing the same ROW) may reduce the risk of collisions because the resulting network of wires is confined to a smaller area and is more visible. Birds only have to make a single ascent to cross lines before resuming their preferred altitude. However, when there is decreased visibility, collision risk for birds may increase where several lines are clustered together. In addition, when there are two shield wires at different heights, and only the higher one is marked, there may be collisions at the lower unmarked shield wire, thus both shield wires may need to be marked (S. Liguori, pers. comm.). See Chapter 5 for examples of risk and reduced risk situations.

STRUCTURE TYPE

Because of the collision risk posed by guyed communication towers (e.g., Shire et al. 2000; Manville 2007a; Gehring et al. 2009; Gehring et al. 2011; Longcore et al. 2012), the question of collision risk associated with guyed power line structures has occasionally been asked. Guy wires on power line structures are used for support and stability especially where a line ends (deadend structure) or changes direction (e.g., makes a 90-degree turn). There is no published information to suggest that guyed power line structures pose a significant collision risk for birds. PacifiCorp has surveyed over 120,000 poles in six states and has not found collision victims at any of the guyed structures (S. Liguori, pers. comm.). Based on exposure alone, the relative short lengths of the guy wires and the low heights on power lines pose much less risk to birds than do the longer, multiple guy wires on communication towers whose height can exceed 300 m (>1,000 ft; Gehring et al. 2011). In addition, some types of lighting on communication towers can attract birds into the collision zone in low visibility weather. Because transmission towers are, with very few exceptions, unlit, they are not expected to have the same risk.

LIGHTING

Studies of bird collisions with communication towers and other tall structures have shown that steady-burning white or red lights can disorient migrating birds at night especially when migration coincides with inclement weather (Manville 2007a, 2009; Gehring et al. 2009, 2011). This disorientation can cause birds to collide with the lighted structure, guy wires on a communication tower, or each other. It can also cause the birds to circle the light source, which may also result in exhaustion and injury or death. Collision incidence on lighted communication towers, for example, depends on the type and intensity of the lights (i.e., steady burning, blinking, or strobe) as well as whether the birds are navigating visually or magnetically. In a Michigan communication tower study, extinguishing steady-burning, L-810, red side lights, while leaving on the red, blinking incandescent pilot warning lights, reduced bird collision mortality by up to 72% (Manville 2007a; Gehring et al. 2009). However, any light, including blinking incandescent and strobe lights, can cause some bird attraction, even during clear weather (Manville 2009a).

In the United States, any structure that is ≥60.9 m (200 ft) above ground level is subject to Federal Aviation Administration (FAA) lighting requirements for aviation safety. Transmission towers in the United States are typically <60.9 m (200 ft) tall[12] and do not have lights. However, shorter structures may also require lighting depending on their location (e.g., in proximity to airports). If lighting is used on transmission lines, it should be compatible with FAA regulations, the Canadian Aviation Regulation, and USFWS bird protection guidelines, and these agencies should be consulted on lighting. The FAA no longer recommends using L-810 steady-burning red lights.[13] In general, the USFWS recommends avoiding lights, particularly steady-burning lights, and using motion- and heat-sensitive lighting where feasible (e.g., for infrastructure security lighting).

[12] Some structures exceed 60.1 m (200 ft) in height, especially at river crossings and to clear other lines that might otherwise intersect (M. Schriner, pers. comm.; D. Bouchard, pers. comm.).

[13] This change is expected to be included in the revision to the FAA's 2007 lighting circular, which is underway at this time (2012). As a preliminary step, in June 2012 the FAA published the results of its pilot conspicuity studies on the elimination of steady-burning red (L-810) side lights at communication towers.

CHAPTER 5

Minimizing Collision Risks

IN THIS CHAPTER

- Opportunities for Minimizing Collision Risks
- Modifying Existing Power Lines
- Planning New Power Lines
- Public Participation to Address Social and Cultural Issues

There are a number of design and engineering strategies for minimizing collision risk with power lines. This chapter introduces evaluation studies and risk reduction strategies for modifying existing lines and planning new lines. This chapter also discusses how to address social and cultural issues through public participation programs.

OPPORTUNITIES FOR MINIMIZING COLLISION RISKS

By working together, engineers and biologists can identify and address collision issues when modifying existing lines and planning new lines (Figure 5.1). Collision issues typically develop or are discovered long after a power line is built, which makes minimizing collision risk more difficult. However, early evaluation of factors that influence collisions (see Chapter 4) can reduce collision potential and may reduce the need for costly modifications later.

PREVIOUS VIEW

Engineers and biologists can reduce collisions when…

Modifying Existing Power Lines	Planning New Power Lines
Evaluation studies include: • Collision monitoring to examine the causes and conditions associated with the risk and to help determine the type and effectiveness of modifications. • Avian risk assessment and spatial analysis to prioritize line segments for modification.	*Evaluation studies include:* • Spatial analysis that considers habitat variables, species, behavior, and other factors to help choose the optimal route. • Field assessment to identify species, abundance, and high bird-use areas. • Avian risk assessment to evaluate collision risk along potential routes.
Risk reduction options include: • Line marking to increase the visibility of the line. • Managing surrounding land to influence bird use. • Removing the shield wire if lightning is not an issue or if lightning arresters can be used instead. • Increasing the diameter or changing the configuration of wires when a line is being rebuilt. • Rerouting the line if all other attempts have been exhausted and populations are significantly impacted. • Burying the lines if feasible and warranted.	*Risk reduction options include:* • Line placement that takes migratory patterns and high bird-use areas into account. • Line orientation that considers biological and environmental factors such as bird flight paths, prevailing winds, and topographical features. • Line configuration that reduces vertical spread of lines, clusters multiple lines in the same right-of-way (ROW), increases the visibility of lines, and/or decreases the span length if such options are feasible. • Line marking to increase the visibility of the line. • Burying lines if feasible and warranted.

FIGURE 5.1: Opportunities and strategies for minimizing collision risks.

MODIFYING EXISTING POWER LINES

EVALUATION STUDIES FOR LINE MODIFICATIONS

If a significant collision risk has been observed along a segment of line, it may be possible to eliminate or minimize the risk by modifying the line in various ways. Line modifications should be supported by collision monitoring studies that examine the causes and conditions associated with a high collision rate (e.g., bird species involved, avian use patterns, mortality rates, weather, and biological significance of mortality levels). Although collision monitoring study methods must be tailored to site-specific biological, environmental, and engineering factors (see Chapter 4), basic, standardized ornithological field survey procedures should be used to produce results that would be comparable to other studies. Appendix B presents considerations and issues for designing site-specific

Comparing the Effectiveness of Line Modifications

Assessments of line modification effectiveness are often based on pre- and post-modification mortality (Rigby 1978; Beaulaurier 1981; Archibald 1987; Brown et al. 1987). Although evaluations based on casual observations or limited sampling of collisions contribute to the knowledge of line modification effectiveness, more rigorous studies are necessary to adequately compare the effectiveness of various measures (e.g., Crowder 2000; Yee 2007, 2008; Ventana Wildlife Society 2009; and Pandey et al. 2008).

study methods for collision monitoring. Once monitoring data are collected, line modification options can be evaluated to identify, quantify, and balance existing risks with the effectiveness and risks posed by the modifications.

Collision Monitoring Studies

To design a collision monitoring study, a number of key questions need to be answered:

- What species is/are at risk?
- What is the magnitude of risk?
- Does this risk contribute to population level impacts?
- What biological, environmental, and engineering factors contribute to collision risk?
- Is the study protocol scientifically sound?
- What are the regulatory and policy considerations of collisions?
- What methods effectively minimize collisions for new and existing power lines?

Collision monitoring results should include the following information:

- Collision rates among species and between sexes and ages (if known) within a single species
- Collision rates expressed as the number of bird collisions relative to the number of birds that are exposed to the line in the strike zone, i.e., collisions/flybys
- Biological, environmental, and engineering factors affecting collision risks (see Chapter 4)
- Mortality corrected for site-specific sampling bias (see Appendix B)
- Behavioral responses of different species to the lines and to line marking devices or other modifications
- Effectiveness of line marking devices based on changes in mortality after marking devices were installed or other line modifications were made

These and other monitoring considerations are discussed in greater detail in Appendix B.

To understand the mortality risk for an entire line, it is essential to study representative segments of the line rather than focusing only on high collision segments, since doing so will overestimate the overall mortality risk. The study method should ensure that test and control segments are of comparable length and that they have as much environmental homogeneity as possible (see Appendix B). On lines with high environmental variability across their length, stratified random sampling may allow the investigator to treat the segments similarly enough to collect meaningful data.

The greatest problem faced by researchers in most field studies is controlling for external variables (e.g., Alonso and Alonso 1999; Jenkins et al. 2010; Barrientos et al. 2011). The results of Brown and Drewien (1995) support the hypothesis of Thompson (1978) that collision rates are not predictable from one study to another and one season to another. They found that rates varied among species, seasons, and years and attributed much of the variability to changes in the local environment, which, in turn, influenced bird densities (see also Blair 1996). This suggests that, ideally, studies should compare test and control line segments within the same time period.

Regardless of whether assessments are made before or after line modification or by using test and control segments, collision risk comparisons are most meaningful if collisions are expressed in relation to bird numbers or, preferably, flybys. This allows a collision rate to be calculated. Where feasible, observations of birds' avoidance behavior when crossing the lines are valuable in understanding how a line affects flight behavior. Actual mortality may be low, which presents a statistical challenge in comparing retrofitting options. This condition should be anticipated and integrated into the study design (see Appendix B).

Collision monitoring studies should incorporate the basic methods used in other mortality evaluations (see Appendix B) including:

- Defining the collision zone for birds crossing lines
- Establishing an adequate search area for mortalities (increasing with the height of the line)
- Obtaining sampling bias estimates for injuries, searcher efficiency, scavenger removal, and habitat differences

Evaluation of bird behavior at marked and unmarked lines provides insight to collision rates. Morkill and Anderson (1991) and Brown and Drewien (1995) demonstrated that bird responses varied with marked and unmarked lines. Observations should be made on marked and unmarked portions simultaneously to minimize environmental variability. For example, Deng and Frederick (2001) showed that the number of birds flying above or below marked and unmarked lines was not statistically significant; however, they observed that the birds approaching a marked line reacted earlier than birds approaching an unmarked line.

Behavioral criteria evaluated may include:

- Type of reaction to lines
- Distance from the line that the reaction occurred
- Height above the line when crossing

Because these estimates require evaluations by observers, it is important to standardize survey procedures (see Appendix B). All observers should be given training and practice time before the study begins and, when possible, the same observers should be used throughout the study. Brown and Drewien (1995) found that most observers required about 12 hours of practice before they became consistent. As an alternative to field observers, the Bird Strike Indicator (BSI), a vibration sensing and recording tool, can be installed on lines to detect bird strikes (see box, page 57). However, the BSI does not identify what species struck the line; hence, mortality monitoring or field observations, which would also reveal pre-strike behavior, would be required.

Avian Risk Assessment and Spatial Analysis

Avian risk assessment and spatial analysis can be used to prioritize segments of line for modification. See *Evaluation Studies for Siting New Power Lines* on page 64.

OPTIONS FOR MODIFYING EXISTING LINES

Potential options for line modification include line marking, managing surrounding land, removing the shield wire, changing the diameter or configuration of wires, and rerouting or burying existing lines where feasible. Utilities are encouraged to work with wildlife agencies (see Chapter 3) to evaluate collision risks to species of concern and options for reducing those risks. Typically, the first option is marking high risk segments of the line and/or managing the surrounding lands. Redesigning, reframing, relocating, or